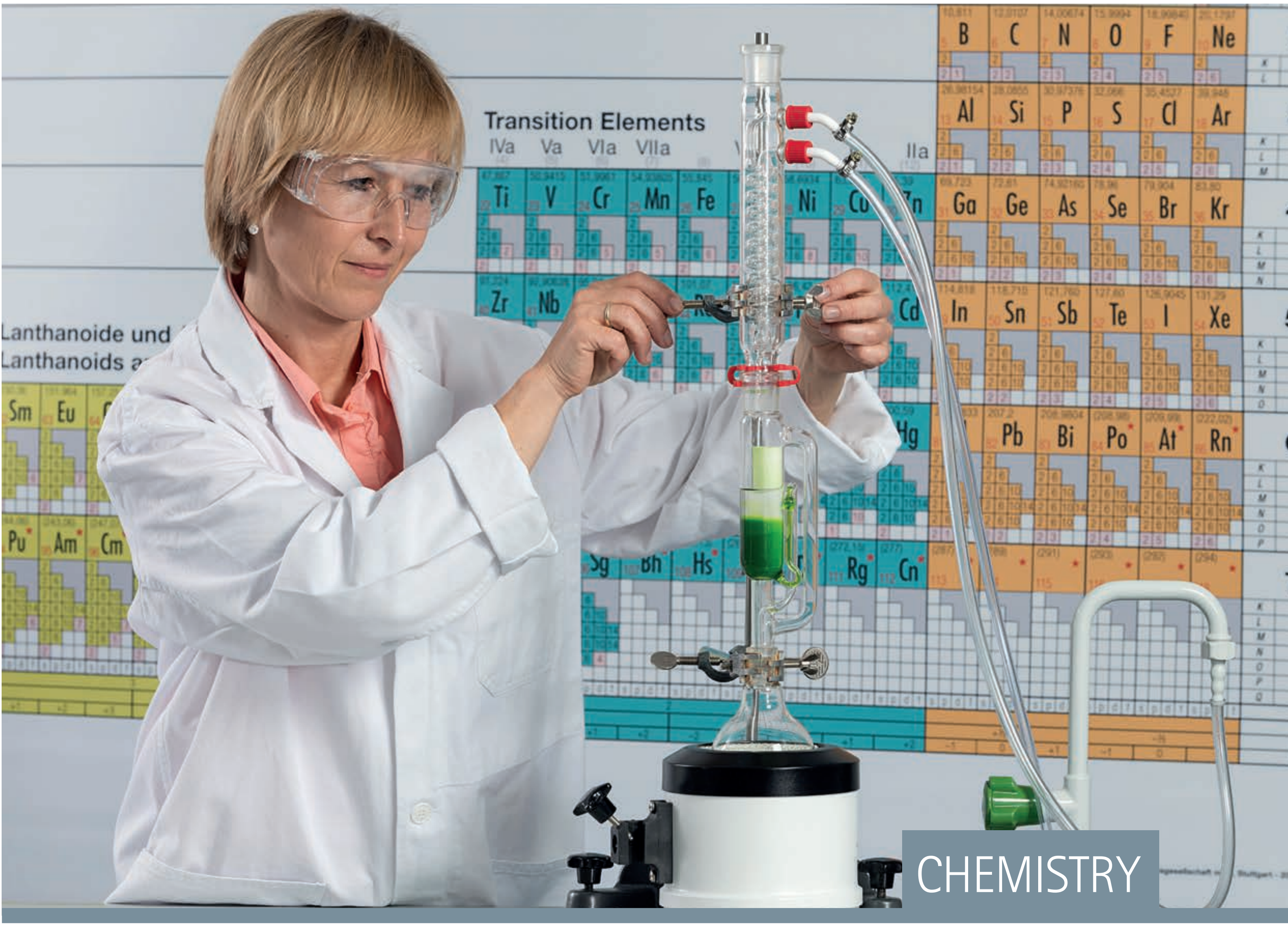
LEYBOLD®

CHEMISTRY EXPERIMENTS



CHEMISTRY

FOR DEMONSTRATION IN SCHOOLS AND UNIVERSITIES

LD DIDACTIC

CHEMISTRY

WITH LEYBOLD



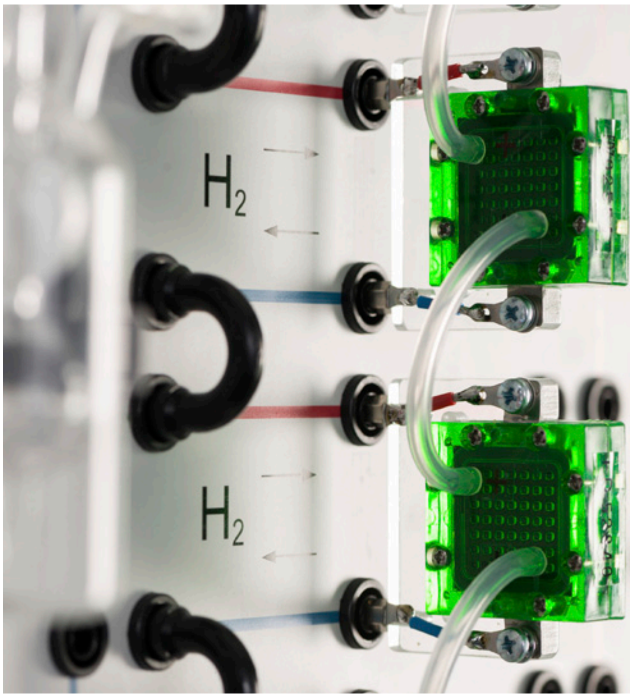
LEYBOLD products bring classroom instructions to life and help teachers prepare and present course content. This catalogue provides an overview of the broad range of equipment for teaching chemistry.

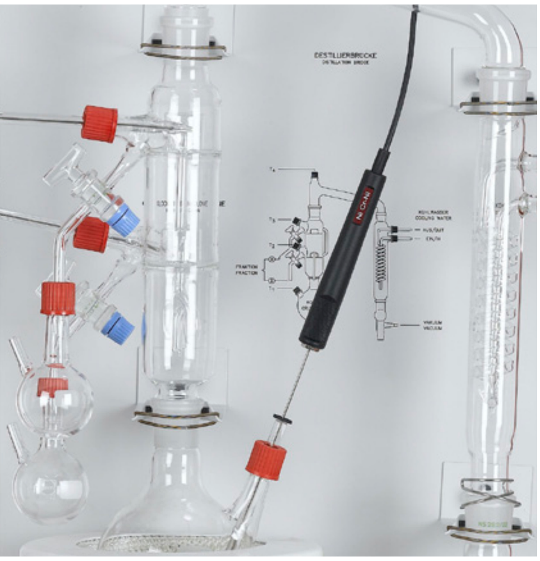
More than 100 experiments designed for demonstrations and hands-on experimentation are highlighted. We present each experiment with the complete list of equipment it requires. The instructions which explain how to carry out the experiments are available on our website.

At LEYBOLD you will find a comprehensive system of chemistry experiments for students. We offer student-based solutions for secondary school levels.

CONTENTS

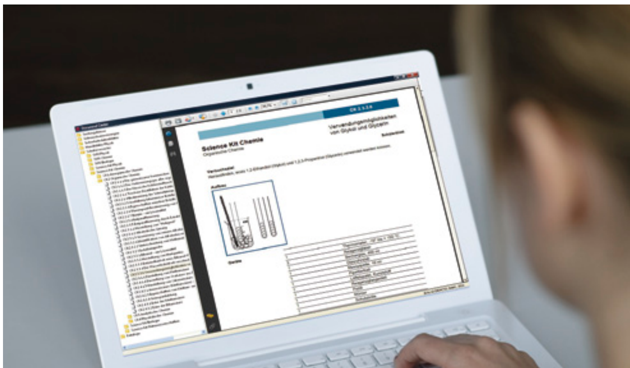
INTRODUCTION





DEMONSTRATION EXPERIMENTS

APPENDIX



EXPERIMENTAL CHEMISTRY WITH LEYBOLD



It takes experiments to bring a chemistry class to life. Ideally, they should alternate between ones carried out by the students themselves and ones presented by the teacher.

This catalogue presents our full range of demonstration experiments. For detailed information about our experiment systems for students, please refer to our website. We will of course also be glad to advise you in person.

Videos about new product features and experiments are posted regularly on the LD DIDACTIC YouTube Channel.

500 EXPERIMENTS FOR SECONDARY SCHOOL STUDENTS



MORE THAN 100 DEMONSTRATION EXPERIMENTS FOR SCHOOLS AND UNIVERSITIES

- For classroom instruction in schools and universities
- Including handout sheets indicating how to conduct the experiment



- Grouped according to different levels of knowledge
  - 100 experiments in science kits for secondary school students
  - 400 experiments in natural science experiments for high school and preparatory school students
- General topics, e.g. inorganic and organic chemistry
- Special topics, e.g. chemistry of detergents and foodstuffs

STUDENT EXPERIMENTS CHEMISTRY

HIGHER EDUCATION UP TO UNIVERSITY LEVEL WITH ADVANCED SCIENCE KITS



400
EXPERIMENTS

With about 400 experiments, both basic and advanced aspects of chemistry are handled in the areas of inorganic chemistry, organic chemistry, analytical chemistry, physical chemistry, chemical processes, chemistry of detergents and foodstuffs.





SECONDARY SCHOOL WITH BASIC SCIENCE KITS

QUICK AND EASY SET-UP AND TEARDOWN

EXPERIMENT LITERATURE ADAPTED TO STUDENTS AS PDF OR MASTER COPY IN THE DOCUMENT CENTER

FEW DEVICES, MANY EXPERIMENTS

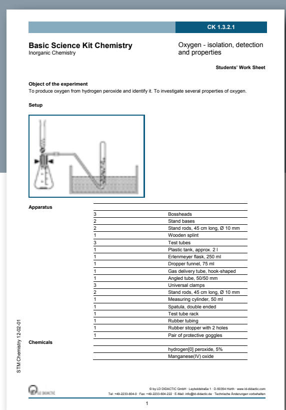


100 EXPERIMENTS

FURTHER INFORMATION CAN BE FOUND ON WWW.LD-DIDACTIC.COM

With about 100 experiments basic aspects of chemistry are handled in the areas of inorganic chemistry, organic chemistry, analytical chemistry and physical chemistry.





CK 1.3.2.1

Basic Science Kit Chemistry
Inorganic Chemistry

Oxygen - isolation, detection and properties

Students' Work Sheet

Object of the experiment
To produce oxygen from hydrogen peroxide and identify it. To investigate several properties of oxygen.

Setup

Apparatus

3	Bossheads
2	Stand bases
2	Stand rods, 45 cm long, Ø 10 mm
1	Wooden splint
3	Test tubes
1	Plastic tank, approx. 2 l
1	Erlenmeyer flask, 250 ml
1	Dropper funnel, 75 ml
1	Gas delivery tube, hook-shaped
1	Angled tube, 50/50 mm
3	Universal clamps
2	Stand rods, 45 cm long, Ø 10 mm
1	Measuring cylinder, 50 ml
1	Spatula, double ended
1	Test tube rack
1	Rubber tubing
1	Rubber stopper with 2 holes
1	Pair of protective goggles

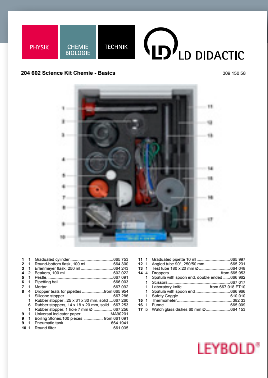
Chemicals

	hydrogen[0] peroxide, 5%
	Manganese(IV) oxide

STM Chemistry 12-02-01

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Tel: +49-2233-604-0 · Fax: +49-2233-604-222 · E-Mail: info@ld-didactic.de · Technische Änderungen vorbehalten

1



WITH

ADVANCED SCIENCE KITS CHEMISTRY

FOR HIGHER EDUCATION

400 EXPERIMENTS

STUDENTS' EXPERIMENTS FOR SECONDARY SCHOOLS

OVERVIEW OF THE TOPICS

INORGANIC CHEMISTRY

Topics	Experiments
Basic experiments/ separation experiments	
Properties of substances	3
Separation of substances	10
Water	
Water as a solvent	6
Water conditioning	5
Air, gases and their properties	
Air and combustion	3
Preparation, test and use of different gases	1
Acids and bases	
Production, test and effects of acids	4
Bases - preparation and properties	5
Salts	
Salt formation	4
Properties and use of salts	3
Metals and non-metals	
Properties and use of metals and non-metalls	13

Number of experiments **57**

ORGANIC CHEMISTRY

Topics	Experiments
Preliminary tests	
Tests for carbon	3
Test for other elements	2
Hydrocarbons	
Properties of hydrocarbons	5
Production of hydrocarbons from crude oil	8
Processing of crude oil fractions	5
Alcohols, aldehydes and ketones	
Production of alcohols	7
Properties and use of alcohols	6
Preparation and properties of aldehydes and ketones	3
Carboxylic acids and esters	
Preparation of carboxylic acids	5
Properties and use of carboxylic acids	8
Production and properties of esters	5

Number of experiments **57**

ANALYTICAL CHEMISTRY

Topics	Experiments
Preliminary tests	
Flame colouration and blowpipe test	2
Borax bead and oxidation melt	2
Test for anions and cations	11
Chromatography	
Column, paper and thin-layer chromatography	9

Number of experiments **24**

CHEMISTRY OF SOAPS AND DETERGENTS

Topics	Experiments
Production of soaps	
Components of soaps	2
Production and processing of soaps	4
The washing and cleaning effects of soaps	
Properties of soaps	7
Factors influencing the washing process	3
Disadvantages and limits to the use of soaps	
Reactions when adding salts and acids	2
Influence of water hardness	3
Other disadvantages	2
Modern washing powders	
Modern tensides	2
Composition of modern washing powders	8
Washing agents and environment	
Environmental load due to tensides and additives	5

Number of experiments **38**

PHYSICAL CHEMISTRY

Topics	Experiments
Electrochemical reactions	14
Particle motion and energy	
Particle motion	4
Chemical reactions and energy	6

Number of experiments **24**

CHEMICAL PROCESSES

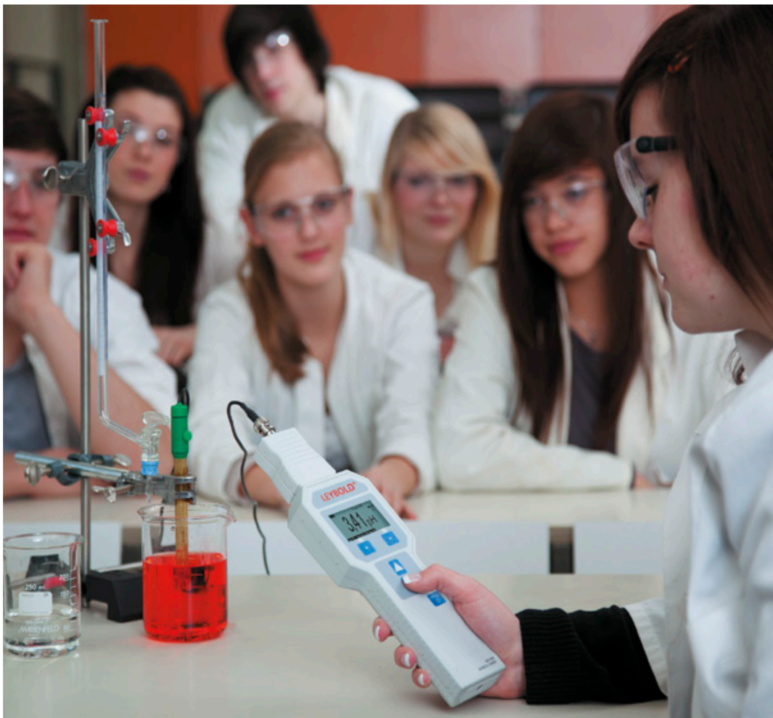
Topics	Experiments
Inorganic key chemicals	4
Building materials	
Lime	4
Cement, concrete and gypsum	6
Glass and ceramics	
Glasses	6
Loam and clay	2
Metals - ores	
Preparation of metals	3
Alloys	2
Chemistry of black and white photography	
Basics of black and white photography	4
Production of photographic materials	4
Identification and recycling of silver salts	2
Fertilizers	4

Number of experiments **41**

CHEMISTRY OF FOODSTUFFS

Topics	Experiments
Fats	
Fat extraction and properties of fats	10
Foodstuffs containing fats	4
Analysis of fats	8
Associated materials of fats	4
Carbohydrates	
Properties and identification	3
Polysaccharides and monosaccharides	11
Starch and cellulose	9
Pectin	3
Types of sugar and honey	4
The process of baking	2
Proteins	
Preparation and properties of proteins	4
Types of proteins	6
Additives and associated agents	
Minerals and vitamins	13
Spices and substances similar to spices	7
Stimulants	
Alcohol	6
Caffeine and theobromine	13
Changes in foodstuffs	
Aging of fats	2
Enzymatic reactions	4
Additives	
Food preservatives	6
Sweeteners and food colourings	7
Other additives	4
Water	
Properties and contents	6
Analysis of foodstuffs	
Chromatography	24
Enzymatic test pocedures	3

Number of experiments **163**



SECONDARY EDUCTION WITH

BASIC SCIENCE KITS CHEMISTRY

STUDENTS' EXPERIMENTS FOR SECONDARY SCHOOLS

100 EXPERIMENTS



OVERVIEW OF THE TOPICS

INORGANIC CHEMISTRY

Topics	Experiments
Basic experiments/separation experiments	
Properties of substances	3
Substance mixtures	2
Water	
Water as a solvent	5
Analysis, synthesis and detection of water	2
Air, gases and their properties	
Air and combustion	2
Preparation, test and use of different gases	4
Acids and bases	
Production, test and effects of acids and bases	3
Bases - preparation and properties	4
Salts	
Salt formation	5
Properties and use of salts	3
Metals and non-metals	
Properties and use of metals	8
Properties and use of non-metalls	4

Number of Experiments **53**

ORGANIC CHEMISTRY

Topics	Experiments
Preliminary tests	
Tests for carbon	3
Hydrocarbons	
Properties of hydrocarbons	2
Production of hydrocarbons from crude oil	5
Processing of crude oil fractions	2
Alcohols, aldehydes and ketones	
Production of alcohols	3
Test for alcohol	3
Preparation and properties of alcohols	5
Carboxylic acids and esters	
Preparation of carboxylic acids	3
Properties and use of carboxylic acids	3
Production and properties of esters	2

Number of Experiments **31**

Displayed experiment:
Simple destillation



ANALYTICAL CHEMISTRY

Topics	Experiments
Preliminary tests	
Flame colouration	2
Borax bead	1
Chromatography	
Paper and thin-layer chromatography	2
Titration	5

Number of Experiments **10**

PHYSICAL CHEMISTRY

Topics	Experiments
Electrochemical reactions	
Electrolytic cells	3
Particle motion and energy	
Particle motion	2
Chemical reactions and energy	2

Number of Experiments **7**

CASSY - THE SYSTEM



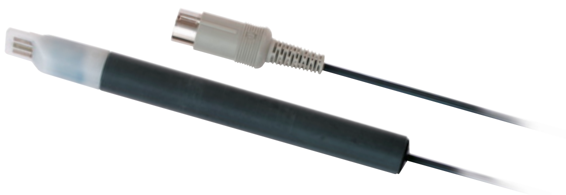


COMPUTER-ASSISTED EXPERIMENTING

- modular and flexible
- for all levels of education and all requirements – from secondary school to university















Sensors for chemistry measurements are, amongst others: Immersion photometer, pH electrode, temperature probe, current and voltage sensor, drop counter and conductivity sensor.

BASIC UNITS

USABLE WITH OR WITHOUT COMPUTER

1.

SENSO

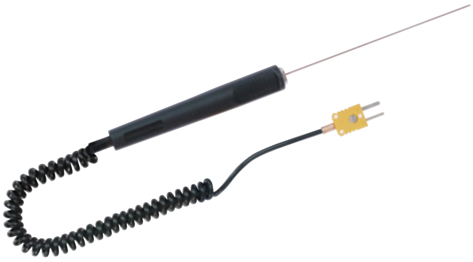
FOR ALL MEASURING TASKS



BENEFITS
AT A GLANCE

- many measurements are possible due to our extensive range of sensors
- for demonstration and students' experiments
- easy and intuitive operation









CASSY Lab 2:
Measuring and analysing software suitable for all devices and sensors.



RS

G

2.

TEACHWARE

DATA ACQUISITION,
ANALYSING AND
EXPERIMENT LITERATURE

3.

STAND SYSTEMS

FOR EVERY CLASSROOM SITUATION



BENEFITS AT A GLANCE

- Optimal work safety through stable, torsion-resistant construction
- Easy to set up thanks to pre-set assembly axes
- Can be adapted to fit the special requirements of each classroom situation

THREE VARIANTS

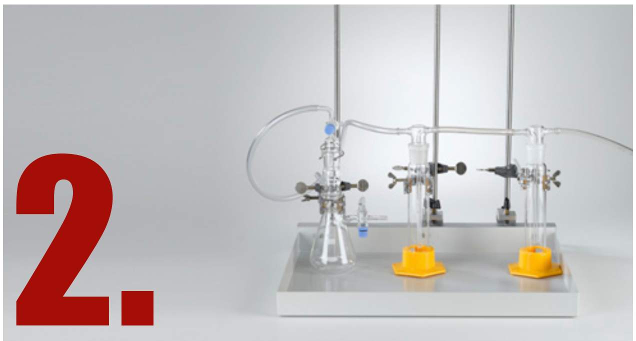


SET-UP WITH BASE RAILS

FOR DEMONSTRATION EXPERIMENTS ON A SINGLE RAIL

The base rail makes it easy to create large set-ups for demonstrations. The stability of the system comes from a solid T-profile made of anodised aluminium, which enables safe set-ups even with heavy components.

- Three different base rails are available for different sized set-ups (110 mm, 550 mm and 950 mm).
- Even large set-ups can be assembled on a single base rail.
- Completely assembled systems can be moved, for example, from a preparation area into the classroom or stored in a cabinet.
- The base rails can also be used as an optical test bench.



SET-UP ON EXPERIMENT TRAY WITH INTEGRATED RAILS

FOR EXPERIMENTS WITH LIQUIDS

The experiment tray is suitable for experiments using liquids.

- The experiment tray acts as a containment basin in case of chemical spills or glass breaks.
- The integrated rails save time when setting up experiments on the experiment tray.
- Fitting universal clamps onto the angular mounting rail makes it possible to install vertical stands.
- The stable, torsion-free construction also makes it possible to move completely assembled systems.



SET-UP ON STAND BASES MADE OF PLASTIC

FOR EXPERIMENTS CARRIED OUT BY STUDENTS

This stand system has been specially designed for use in experiments carried out by students themselves.

- The stand bases used are very lightweight.
- Thanks to double strut construction, the assembled stand system is almost completely torsion-free, which makes it possible to move apparatus before they have been completely set up.
- The stand can be disassembled to save space during storage.
- The stand is made of solid materials (ABS plastic and stainless steel).
- The stand materials are used in chemistry, biology and physics experiments.

CHEMISTRY PANEL SYSTEM

MODULAR AND CLEARLY ARRANGED DEMONSTRATION EXPERIMENTS

- Clearly arranged mounting systems for experiments with plain background and no disruptive stand materials
- Easy set-up in just seconds
- Predefined distances eliminate the need for painstaking glassware adjustments
- Extremely rapid assembly or modification of the experiment set-ups – even during class
- Reduced preparation time
- GL screw connectors ensure secure, leak-tight connections between the individual modules – no more fused ground glass joints
- Glassware is mounted securely to the experimentation boards – this reduces the risk of breakage
- Safe and convenient storage in the cabinet with groove profiles

FAST AND EASY SET-UP

FAST AND SAFE SET-UP BASED ON MODULES

1.

Install the experiment panels in the profile rails of the CPS frame.

Installing the experimentation panels in the CPS frame.







The new magnetic holders make it possible to assemble experiment set-ups on an individual basis.

ASSEMBLY AND MODIFICATION OF THE EQUIPMENT IN JUST SECONDS WITH THE NEW MAGNETIC HOLDERS

FAST INSTALLATION AND REMOVAL OF GLASSWARE USING FLEXIBLE CLAMPS AND MAGNETIC HOLDERS

2. Push a GL connector cap (silicone seals are included) onto a glass component (e.g. three-way stopcock) and screw it onto the glass connector.

3. Slide the second experiment panel up to the first panel and screw the glass component with the attached GL connector cap (e.g. a gas syringe) onto the glass connector. The glassware fits together perfectly because the dimensions are standardised. This ensures secure, leak-tight connections between the glassware of the two experimentation panels.

CPS FRAMES

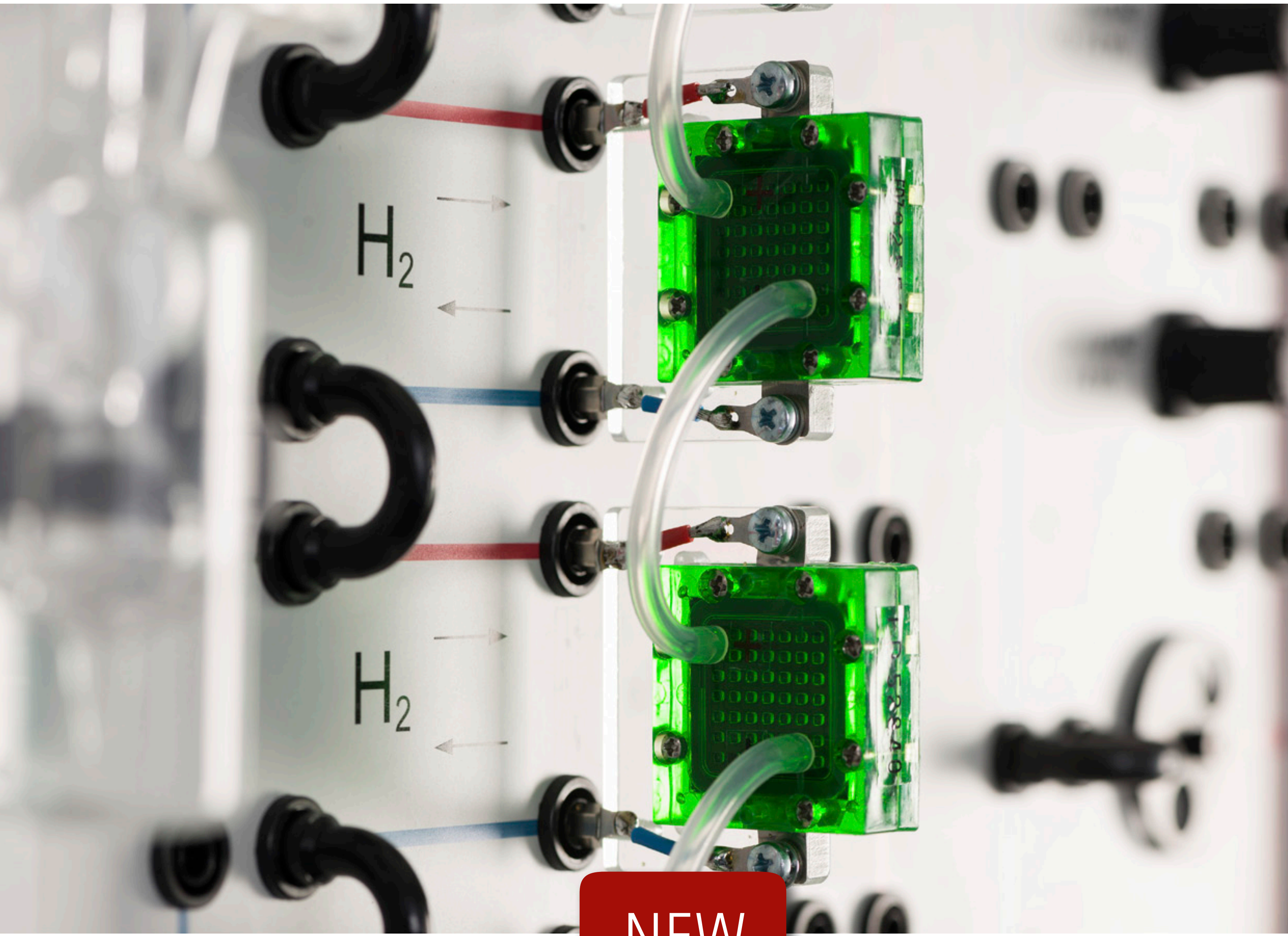
- Accommodate any number of experimentation panels
- Fit inside every fume cupboard:
  50 cm wide for smaller experiments
  97 cm wide for larger experiments



TEACHING

FUEL CELL TECHNOLOGY

THROUGH DEMONSTRATION EXPERIMENTS



CPS fuel cell stack (666 4812).

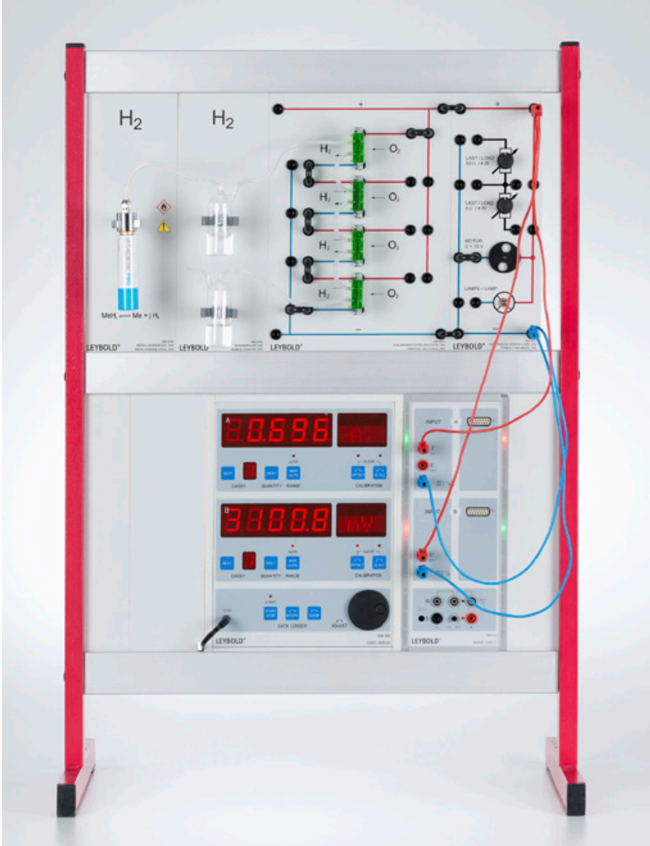
NEW

CHARGING HYDROGEN QUICKLY AND EASILY

NEW

WITH THE LEYBOLD DEMONSTRATION EXPERIMENT SET-UP

- New PEM fuel cell stack made of four separate cells which can be connected together quickly, either in series or in parallel
- Clearly arranged and visible from a distance: ideally suited for demonstrations or project work
- In combination with the electrical consumer module: simple recording of characteristic curves and measurement of efficiencies
- Hydrogen from the HydroStik PRO, no gas cylinder required



Recording of characteristic curves using Sensor CASSY 2 and CASSY Display (no computer necessary).

HydroStik PRO, CPS	666 4795
Bubble counter, CPS	666 4794
PEM fuel cell stack, CPS	666 4812
Electrical load, CPS	666 4831
HydroFill PRO	666 4798

THE EASY WAY TO PRODUCE ALL THE H_2 YOU NEED RIGHT FROM THE WALL SOCKET – AND SAVE SPACE AT THE SAME TIME!



The HydroFill PRO (666 4798) supplies hydrogen by electrolysis of distilled water. The hydrogen is stored directly in the HydroStik PRO (666 4796) as a metal hydride and can be transported and dispensed safely.

HydroFill PRO Video at the LD DIDACTIC YouTube Channel.

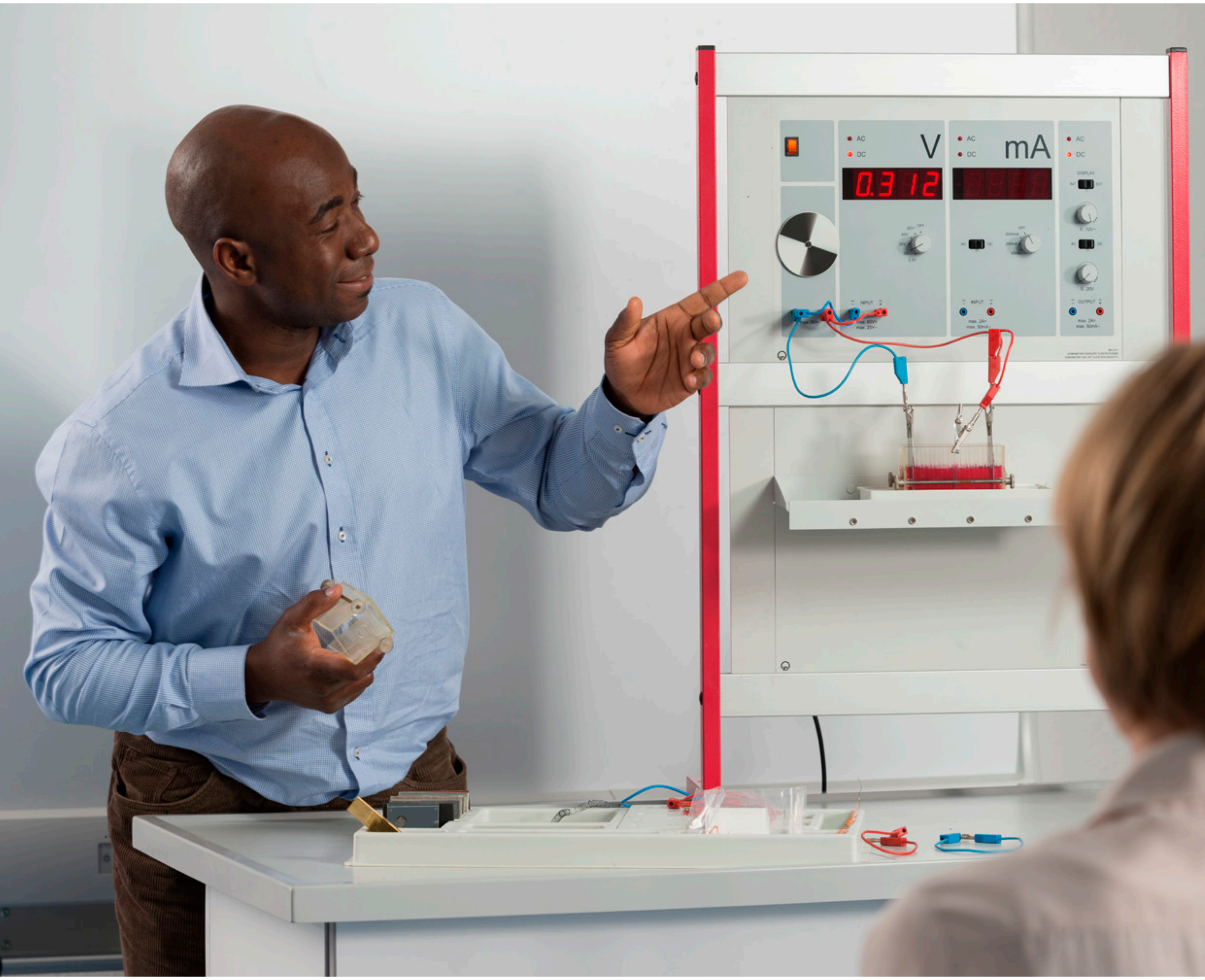
Charging the HydroStik PRO – as easy as a mobile phone:

1. Insert the HydroFill PRO into the charging station.
2. Charge it with hydrogen for 4 to 6 hours.
3. Use the hydrogen for experiments.

TEACHING

ELECTROCHEMISTRY

THROUGH DEMONSTRATION EXPERIMENTS



The electrochemistry demo system is ideal for demonstration experiments, because the experiments are clearly visible even from the back of the classroom.

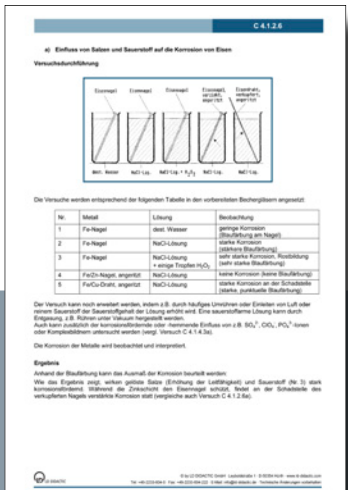
WITH THE ELECTROCHEMISTRY DEMONSTRATION SYSTEM

- The demo system fulfils 3 functions:
  - It includes two separate instruments to measure voltage and current.
  - It operates as a power supply for direct and alternating current.
  - A small integrated motor with segmented disc serves as a power indicator.
- Its large display makes it clearly visible even from a distance of 10 metres.
- With the accessory set and experiment instructions, up to 40 experiments can be carried out.
- Topics
  - Conductivity of solids and liquids
  - Electrochemical series of metals and non-metals
  - Corrosion and corrosion protection
  - Faraday's laws
  - Galvanic cells



The electrochemical demo system can be mounted in a CPS frame. All experiments can then be carried out on the experiment table, which is also mounted in the frame.

Electrochemistry demo, CPS, equipment package	664 4071P
Electrochemistry demo system, CPS	664 4071
Electrochemistry accessory set	664 401
LIT: Electrochemistry demonstration experiments	668 131
Profile frame C50, in two rows, for CPS	666 425
Table for electrochemistry, CPS	666 472



C 4.1.2.6

a) Einfluss von Salzen und Sauerstoff auf die Korrosion von Eisen

Versuchsdurchführung

Die Versuche werden entsprechend der folgenden Tabelle in den vorbereiteten Bechergläsern angesetzt:

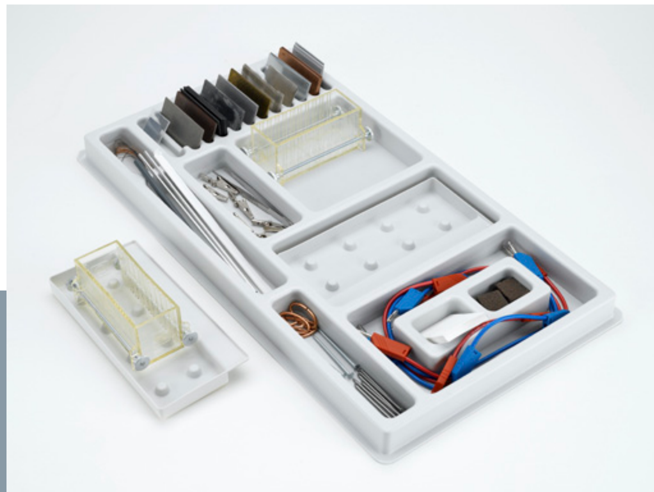
Nr.	Metall	Lösung	Beobachtung
1	Fe-Nagel	dest. Wasser	geringe Korrosion (Blaufärbung am Nagel)
2	Fe-Nagel	NaCl-Lösung	starke Korrosion (stärkere Blaufärbung)
3	Fe-Nagel	NaCl-Lösung + einige Tropfen H_2O_2	sehr starke Korrosion, Rostbildung (sehr starke Blaufärbung)
4	Fe/Zn-Nagel, angeritzt	NaCl-Lösung	keine Korrosion (keine Blaufärbung)
5	Fe/Cu-Draht, angeritzt	NaCl-Lösung	starke Korrosion an der Schadstelle (starke, punktuelle Blaufärbung)

Die Korrosion der Metalle wird beobachtet und interpretiert.

Ergebnis

Anhand der Blaufärbung kann das Ausmaß der Korrosion beurteilt werden.

Experiment instructions (668 131)



Accessory set (664 401)

COMPACT SPECTROMETER

SAVES SPACE AND CAN BE USED FOR A WIDE RANGE OF EXPERIMENTS



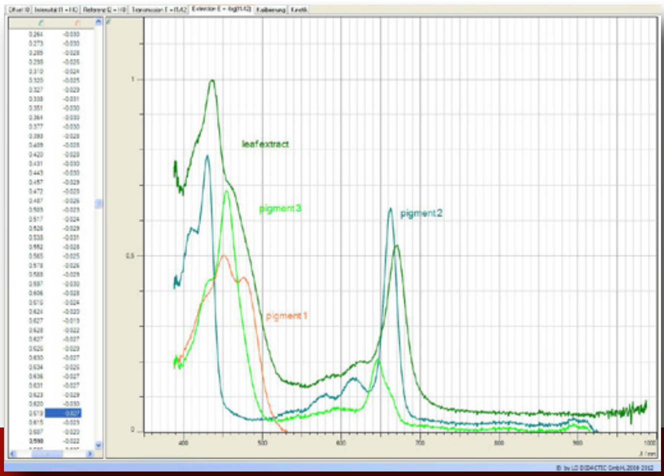
In combination with the fibre optic cable, the spectrometer is particularly well-suited for analysing flame colourations.

FAST AND EASY-TO-INTERPRET SPECTRAL MEASUREMENTS

- Small device with USB connection
- **SpectraLab software:** displays spectra while taking measurements
- Simultaneous measurement of all wavelengths
- Cuvette holder with integrated lamp (optional)
- Example experiments
  - Flame colouration (C1.1.3.7)
  - UV/VIS spectra of dyes (C3.3.1.2)
  - Fluorescence spectra (C3.3.1.3)
  - Determination of pK_a values of indicators (C4.2.2.1)
- Variants for VIS or UV/VIS measurements



The cuvette holder also makes it possible to carry out photometric measurements on small quantities.

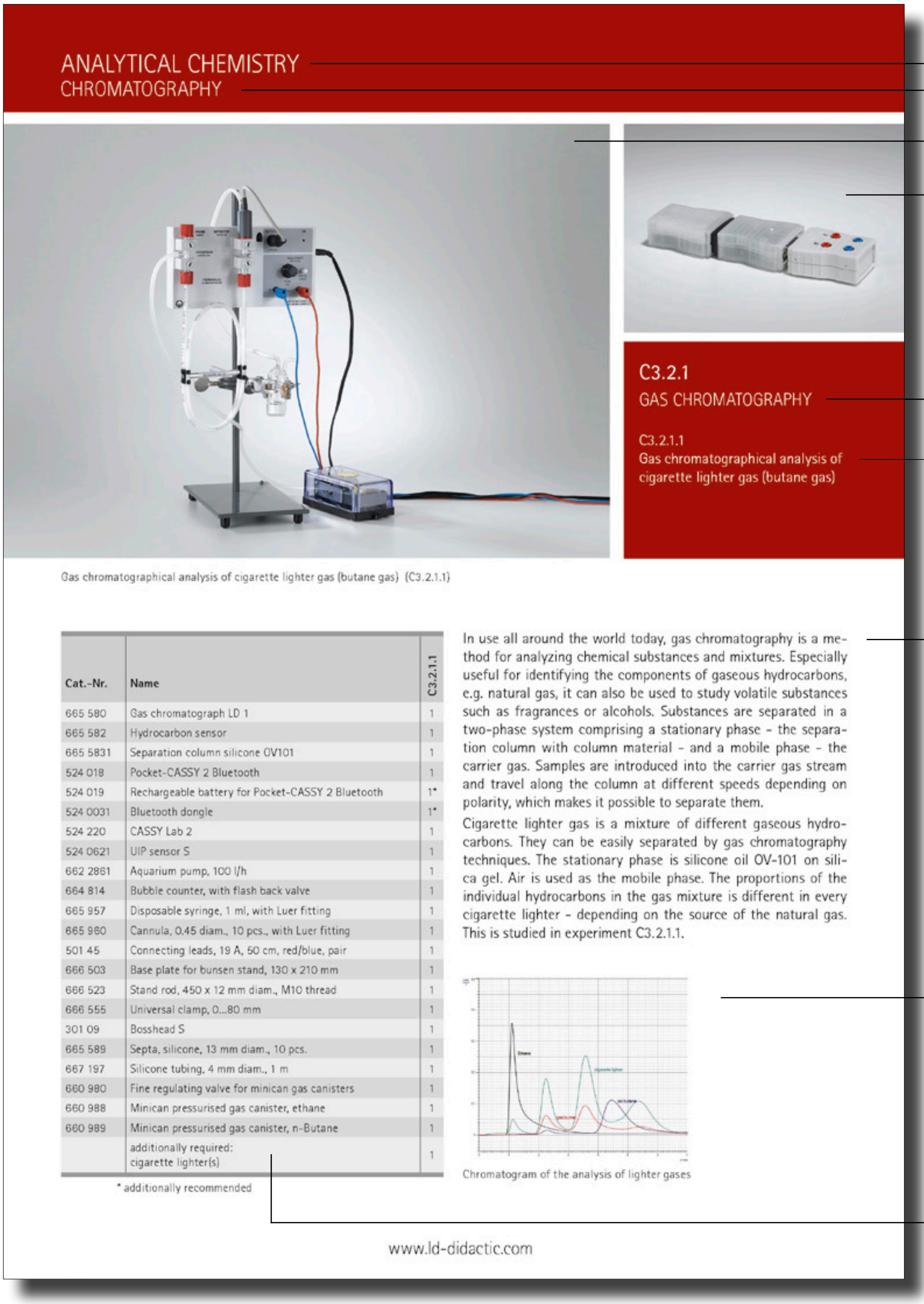


Analysis of leaf pigments with the SpectraLab software.

SpectraLab	467 250
Compact spectrometer, physics	467 251
Compact spectrometer, complete	467 252
Cuvette holder with light source	467 253
Fibre optic cable VIS/NIR	467 254
Compact UV spectrometer, physics	467 261
Compact UV spectrometer, complete	467 262
Cuvette holder with UV light source	467 263
Fibre optic cable, UV	467 264

HOW TO USE THIS CATALOGUE

PAGE STRUCTURE


ANALYTICAL CHEMISTRY
CHROMATOGRAPHY

C3.2.1
GAS CHROMATOGRAPHY

C3.2.1.1
Gas chromatographical analysis of cigarette lighter gas (butane gas)

Gas chromatographical analysis of cigarette lighter gas (butane gas) (C3.2.1.1)

Cat.-Nr.	Name	C3.2.1.1
665 580	Gas chromatograph LD 1	1
665 582	Hydrocarbon sensor	1
665 5831	Separation column silicone OV101	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 0621	UIP sensor S	1
662 2861	Aquarium pump, 100 l/h	1
664 814	Bubble counter, with flash back valve	1
665 957	Disposable syringe, 1 ml, with Luer fitting	1
665 960	Cannula, 0.45 diam., 10 pcs., with Luer fitting	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
666 503	Base plate for bunsen stand, 130 x 210 mm	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp, 0...80 mm	1
301 09	Bosshead S	1
665 589	Septa, silicone, 13 mm diam., 10 pcs.	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
660 980	Fine regulating valve for minican gas canisters	1
660 988	Minican pressurised gas canister, ethane	1
660 989	Minican pressurised gas canister, n-Butane	1
	additionally required: cigarette lighter(s)	1

* additionally recommended

In use all around the world today, gas chromatography is a method for analyzing chemical substances and mixtures. Especially useful for identifying the components of gaseous hydrocarbons, e.g. natural gas, it can also be used to study volatile substances such as fragrances or alcohols. Substances are separated in a two-phase system comprising a stationary phase - the separation column with column material - and a mobile phase - the carrier gas. Samples are introduced into the carrier gas stream and travel along the column at different speeds depending on polarity, which makes it possible to separate them.

Cigarette lighter gas is a mixture of different gaseous hydrocarbons. They can be easily separated by gas chromatography techniques. The stationary phase is silicone oil OV-101 on silica gel. Air is used as the mobile phase. The proportions of the individual hydrocarbons in the gas mixture is different in every cigarette lighter - depending on the source of the natural gas. This is studied in experiment C3.2.1.1.

Chromatogram of the analysis of lighter gases

www.ld-didactic.com

Section
Subsection

Experiment set-up

Measurement option
With computer-assisted experiments, the recommended basic unit is shown (see table on the right).

Topic

Experiment
Each experiment is identified by a C and a four-digit number.

Short description of the experiment

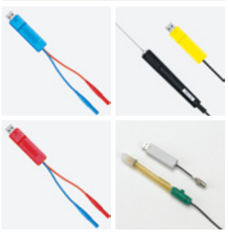
Experiment results

Equipment list

MEASUREMENT OPTIONS WITH CASSY

FOR EACH EXPERIMENT, THE RECOMMENDED BASIC DEVICE APPEARS ON THE RIGHT OF THE EXPERIMENT SET-UP

We offer the right basic device for every classroom instruction situation.

Classroom situation		Basic unit	Number of sensor sockets	Integrated ability to measure	Inte-grated display	Data storage in the unit	Computer interface
Sophisticated demonstration experiments		Sensor-CASSY 2 (524 013)	2	electric current and voltage	no	no	USB
Simple demonstration experiments (also in the fume cupboard) and experiments for students		Pocket-CASSY 2 BT (524 018)	1	none	no	no	wireless (Bluetooth) or USB
Demonstration experiments without a computer		Universal measuring instrument chemistry (531 836)	1	tempera-ture*	yes	no	USB, but measure-ment without computer also possible
Experiments for students and experiments outside of the classroom		Mobile-CASSY (524 009A)	1	none	yes	yes	USB for reading out the data
Experiments for students		Micro-CASSYs (528 11) (528 12) (528 15) (528 18)	Sensor and basic device in one	Voltage Current Temperature pH value	no	no	USB

These coloured fields indicate the main features of the corresponding basic device.

* Temperature probe also required

EXPERIMENTS AT A GLANCE

C1.5 Metals and their properties

Extraction of metals,

Corrosion

Pages 49–51

C1.6 Non-metals and their properties

The oxygen family

Page 52

C1.7 Acids, bases and salts

Acid strengths and pH values,

Salts and ionic compounds

Pages 53–56











C3.5 Quantitative analysis

Potentiometric and acid-base titrations,

Conductometric titrations,

Redox titrations

Pages 87–89

C3.6 Applied analytics

Water analytics,

Air analytics,

Food analytics,

Material analytics

Pages 90–94







C4.6 Transport processes

Osmosis

Page 120





















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C1 GENERAL AND INORGANIC CHEMISTRY



Determination of the relative atomic mass of metals (C1.1.1.1)

C1.1.1
DETERMINATION OF MOLAR MASS

C1.1.1.1
Determination of the relative atomic mass of metals

Cat.-Nr.	Name	C1.1.1.1
664 097	Stoichiometric reaction vessel	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1
665 936	Immersion tube manometer, after Schiele	1
664 352	Topping-up reservoir, 250 ml	1
667 194	Silicone tubing, 7 mm diam., 1 m	1
382 21	Stirring thermometer, -30...+110 °C	1
667 312	Glass connector, 2 x GL 18	1
666 968	Spoon-ended spatula, stainless steel, 180 mm	1
667 027	Tweezers, blunt, 130 mm	1
667 605	Safety screen	1
664 103	Beaker, DURAN, 250 ml, squat	1
665 753	Measuring cylinder, 50 ml, with plastic base	1
666 4659	Adhesive magnetic board, 500 mm	2
666 4662	Spring clips, magnetic, size 3, 11...14 mm	1
666 4665	Spring clips, magnetic, size 7a, 30...32 mm	3
666 425	Panel frame C50, two-level, for CPS	1
667 7988	Analytical balance ABS 80-4, 83:0.0001 g	1
674 6810	Hydrochloric acid, 10 %, 1 l	1
673 1000	Magnesium, ribbon, 25 g	1
661 081	Aluminium, foil, 1 roll	1
671 2000	Calcium, granules, 25 g	1

The realisation that chemical reactions depend not on the mass of a substance but on the number of atoms marks the transition from alchemy to chemistry as a science. In that way, the molar mass can be used to carry out reactions with the right quantity of material.

In experiment C1.1.1.1, the molar mass of some base metals will be determined. In order to do so, those metals - magnesium, for example - will be reacted with acids.

$$Mg + 2\,H^+ \rightarrow Mg^{2+} + H_2$$

Different metals of the same weight produce different quantities of hydrogen. When using the same quantity of material, the same quantities of hydrogen are produced. This way, the relative molar mass of the respective metals can be determined.



Determination of the molar mass of gases (C1.1.1.2)

C1.1.1

DETERMINATION OF MOLAR MASS

C1.1.1.2
Determination of the molar mass of gases

Cat.-Nr.	Name	C1.1.1.2
379 07	Sphere with 2 stop-cocks, glass	1
OHS PU123	Electronic precision balance SPU123	1
667 072	Support ring for 250-ml round flask, cork	1
375 58	Hand vacuum pump	1
665 913	Gas syringe, 100 ml with 1-way stopcock	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
604 434	Silicone tubing, 8 mm diam., 1 m	1
604 510	Hose connector, 4...15 mm	2
667 186	Vacuum rubber tubing, 8 mm diam.	1
604 491	Vacuum tubes, 6 mm diam.	1
660 998	Minican pressurised gas canister, oxygen	1
661 000	Minican pressurised gas canister, nitrogen	1
660 980	Fine regulating valve for minican gas canisters	2
661 082	Stopcock grease, 60 g	1

At constant pressure and constant temperature, any gas occupies the same volume regardless of the type of atom or the composition. So if we know the volume, pressure and temperature, we can then determine the molar mass of gases. The measurement is conducted in experiment C1.1.1.2 with a glass sphere for weighing gases.





C1.1.2
STATES OF MATTER

C1.1.2.1
Melting ice, boiling water

Melting ice, boiling water (C1.1.2.1)

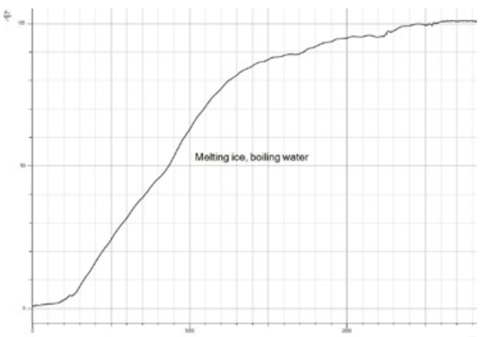
Cat.-Nr.	Name	C1.1.2.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
664 105	Beaker, DURAN, 600 ml, squat	1
666 8471	Magnetic stirrer with hotplate	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp, 0...80 mm	1
301 09	Bosshead S	1
	additionally required: ice PC with Windows XP/Vista/7/8	

* additionally recommended

There are three states of matter: solid, liquid and gas. Solid materials have a stabile outer shape and a definite volume. Liquids have a definite volume but no longer have a solid shape. Gaseous materials have neither a shape nor a volume: they fill up any available space.

At constant pressure, materials transition from one state of matter to the next at a characteristic temperature. Those temperatures are known and listed as the melting point and boiling point.

Experiment C1.1.2.1 examines the behaviour of water at different temperatures. To that end, ice (solid water) is slowly heated until it melts and then evaporates. At the boiling point and the melting point, the temperature does not change until the substance has transitioned completely to the other state. The boiling point and melting point are easy to determine in this way.



Melting and boling curve of water



C1.1.3
STRUCTURE OF MATTER

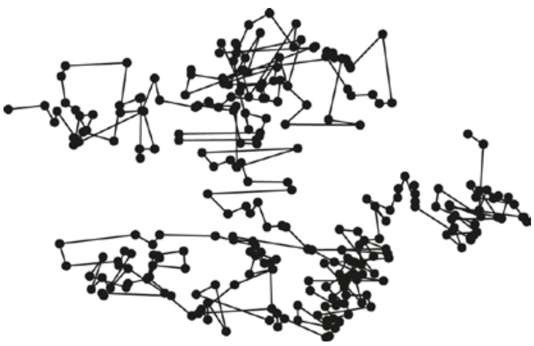
C1.1.3.1
Brownian motion of smoke particles

Brownian motion of smoke particles (C1.1.3.1)

Cat.-Nr.	Name	C1.1.3.1
662 078	Monocular students' microscope M 805	1
372 51	Smoke chamber	1
450 60	Lamp housing with cable	1
450 511	Bulbs, 6 V/30 W, E14, set of 2	1
460 20	Condenser with diaphragm holder	1
521 210	Transformer, 6/12 V	1
300 02	Stand base, V-shaped, small	1

Matter is everything that takes up space and has mass. We distinguish between pure substances and mixtures. Mixtures can be homogeneous or heterogeneous. Pure substances are elements and are made up entirely of the same type of atom. Each atom consists of a core, the nucleus, and a shell, the electron shell.

The speed and direction of a particle floating in a gas changes continuously. *J. Perrin* provided the explanation for this molecular motion, which was discovered by *R. Brown*: it is caused by the impacts of the gas molecules on the particle. The smaller the particle, the livelier the motion. It comprises a translational motion and a similarly changing rotation. In experiment C1.1.3.1, a microscope is used to observe the motion of smoke particles in air.



Schematic diagram of Brownian motion of molecules



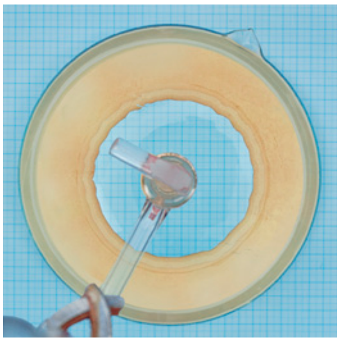
Estimation of the size of oil molecules (C1.1.3.2)

C1.1.3
STRUCTURE OF MATTER

C1.1.3.2
Estimation of the size of oil molecules

Cat.-Nr.	Name	C1.1.3.2
664 179	Crystallisation dish, 230 mm diam., 3500 ml	1
665 844	Burette, amber glass, 10 ml	1
664 110	Beaker, DURAN, 50 ml, tall	1
665 751	Measuring cylinder, 10 ml, with plastic base	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp, 0...80 mm	1
675 3410	Water, pure, 5 l	1
672 1240	Glycerinetrioleate, 100 ml	1
674 2220	Petroleum ether, 40...70 °C, 1 l	1
670 6920	Lycopodium spores, 25 g	1

One of the important questions in atomic physics is the question of the size of the atom. The study of the size of molecules provides experimentally easier access on a manageable magnitude. Experiment C1.1.3.2 uses simple means to estimate the size of molecules from the size of a patch of oil floating on the surface of water.



Determining the area A of the oil spot



Analysis of Rutherford scattering (C1.1.3.4)

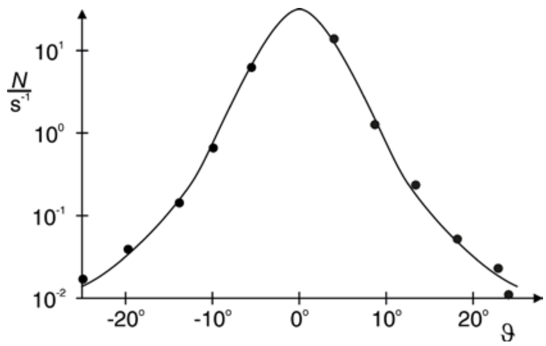
C1.1.3
STRUCTURE OF MATTER

C1.1.3.4
Analysis of Rutherford scattering

Cat.-Nr.	Name	C1.1.3.4
559 820Z	Am-241 preparation, 330 kBq	1
559 56	Rutherford scattering chamber	1
559 52	Aluminium foil in frame	1
559 931	Discriminator preamplifier	1
562 791	Plug-in power supply 12 V AC	1
575 471	Counter S	1
378 73	Rotary-vane vacuum pump S 1.5	1
378 005	T-piece, DN 16 KF	1
378 040ET2	Centring rings (adapters), DN 10/16 KF, set of 2	1
378 045ET2	Centring rings, DN 16 KF, set of 2	1
378 050	Clamping ring, DN 10/16 KF	2
378 771	Air inlet valve, DN 10 KF	1
378 031	Hose nozzle, DN 16 KF	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
501 01	BNC cable, 0.25 m	1
575 24	Screened cable, BNC/4 mm	1
	additionally required: PC with Windows XP/Vista/7/8	1

The fact that an atom is „mostly empty“ was confirmed by *Rutherford*, *Geiger* and *Marsden* in a momentous experiment. They let a parallel bundle of α-particles fall on a very thin sheet of gold foil. In so doing they found that the vast majority of α-particles pass through the gold foil almost without any deflection at all and only very few are deflected to any large degree. They concluded from this that atoms comprise a nearly massless, extended shell and a massive core concentrated practically at a point.

Experiment C1.1.3.4, carries out an observation with an Am-241-preparation in a vacuum chamber. Depending on the scatter angle ϑ the scatter rate $N(\vartheta)$ of the α-particles is measured with a Geiger-Müller tube.



Scattering rate N as a function of the scattering angle delta

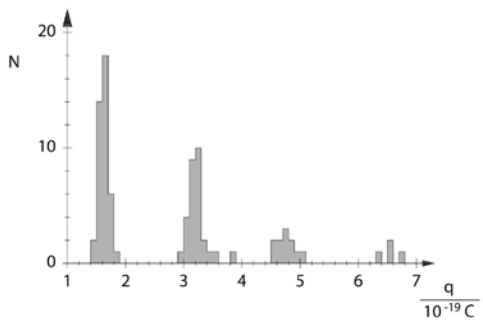


C1.1.3
STRUCTURE OF MATTER

C1.1.3.5
Determination of the elementary electric charge according to Millikan and proof of charge quantisation

Determination of the elementary electric charge according to Millikan and proof of charge quantisation (C1.1.3.5)

Cat.-Nr.	Name	C1.1.3.5
559 412	Millikan apparatus	1
559 421	Millikan supply unit	1
313 033	Electronic stop-clock P	1
501 46	Connecting leads, 19 A, 100 cm, red/blue, pair	3



The histogram reveals the qantum nature of the change

With his famous oil-drop method, R. A. Millikan succeeded in demonstrating the quantum nature of minute amounts of electricity in 1910. He caused charged oil droplets to be suspended in the vertical electric field of a plate capacitor and, on the basis of the radius r and the electric field E, determined the charge q of a suspended droplet:

$$q = \frac{4\pi}{3} \cdot r^3 \cdot \frac{\rho \cdot g}{E}$$

ρ: density of oil
g: gravitanional acceleration

He discovered that q only occurs as a whole multiple of an electron charge e.

In experiment C1.1.3.5, the electric field

$$E = \frac{U}{d}$$

d: plate spacing

is calculated from the voltage U on the plate condenser at which the oil droplet is observed floating straight. To determine the radius, the constant sinking velocity v_1 of the droplet is then measured with the electric field switched off. From the equilibrium between the force of gravity and Stokes' drag, it follows that

$$\frac{4\pi}{3} \cdot r^3 \cdot \rho \cdot g = 6\pi \cdot r \cdot \eta \cdot v_1$$

η: viscosity



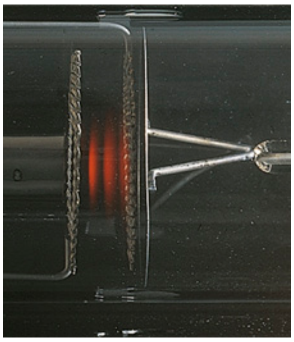
C1.1.3
STRUCTURE OF MATTER

C1.1.3.6
Franck-Hertz experiment

Franck-Hertz experiment (C1.1.3.6)

Cat.-Nr.	Name	C1.1.3.6
555 870	Ne Franck-Hertz tube	1
555 871	Holder with socket and screen	1
555 872	Connecting cable for Ne Franck-Hertz tube	1
555 880	Franck-Hertz supply unit	1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
501 46	Connecting leads, 19 A, 100 cm, red/blue, pair	2
	additionally required: PC with Windows XP/Vista/7/8	1

In 1914, J. Franck and G. Hertz reported observing discontinuous energy emission when electrons passed through mercury vapor, and the resulting emission of the ultraviolet spectral line (λ = 254 nm) of mercury. A few months later, Niels Bohr recognised that their experiment supported his model of the atom. The de-excitation of neon atoms can occur indirectly via intermediate states, with the emission of photons. In this process, the photons have a wavelength in the visible range between red and green. The emitted light can thus be observed with the naked eye. Between the grids G_1 and G_2 reddish luminous layers, clearly separated from one another, can be observed, and their number increases with increasing voltage. These are zones of high excitation density, in which the excited atoms emit spectral light.



Luminous layers between control electrode and acceleration grid



Recording emission spectra of a flame test (C1.1.3.7)

C1.1.3
STRUCTURE OF MATTER

C1.1.3.7
Recording emission spectra of a flame test

Cat.-Nr.	Name	C1.1.3.7
467 251	Compact spectrometer, physics (spectral photometer)	1
460 251	Fibre holder	1
300 11	Saddle base	1
666 731	Gas igniter, mechanical	1
604 5681	Powder spatula, steel, 150 mm	1
667 089	Spotting tile	1
656 017	Teclu burner, universal	1
607 020	Safety gas hose with clamp, 0.5 m	1
673 0840	Magnesia rods, 25 pieces	1
661 088	Salts for flame tests, set of 9	1
674 6950	Hydrochloric acid, 0.1 mol/l, 500 ml	1
	additionally required: PC with Windows XP/Vista/7/8	

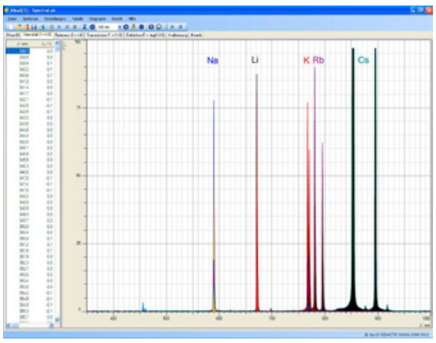
Spectral lines occur when electrons transition from higher to lower energy levels in the shell of excited atoms. The wavelength of the light emitted during the transition is determined by that energy differential:

$$\nu = \frac{E_2 - E_1}{h}$$

h: Planck's constant

Because the energies E_1 and E_2 can only take on discrete values, only photons with discrete frequencies are emitted or absorbed. Taken all together, the frequencies which occur are referred to as the spectrum of the atom. The arrangement of the spectral lines is characteristic for the element concerned.

Experiment C1.1.3.7 investigates flame colourations of metal salts. A compact spectrometer with a USB link to the computer makes it easy to record such transient events and to analyse the emission lines which are produced. Unlike in classical observation with the eye, lines in the IR range can also be identified, e.g. for potassium.



Emission spectra of different metal salts



Conservation of mass in the reaction of marble with acid (C1.2.1.1)

C1.2.1

LAW OF CONSERVATION OF MASS

C1.2.1.1
Conservation of mass in the reaction of marble with acid

Cat.-Nr.	Name	C1.2.1.1
OHT A302	Portable balance traveler™ TA302	1
664 238	Erlenmeyer flask, DURAN, 250 ml, wide neck	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
667 0344	Tweezer, blunt, 145 mm	1
667 243	Rubber balloons, set of 10	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1
673 2500	Marble, pcs., 250 g	1

The law of conservation of mass was formulated in 1789 by Antoine Laurent de Lavoisier: For a chemical reaction in a closed system, the sum of the masses of the starting materials is equal to the sum of the masses of the products.

Experiment C1.2.1.1 demonstrates that in a chemical reaction the total mass of the substances involved in the reaction remains unchanged. In the experiment, hydrochloric acid is pipetted into a test tube. Pieces of marble are introduced into a balloon. The reaction is started by tipping the pieces of marble into the acid. Although bubbles form, it can be observed that no mass is lost.



Synthesis of magnesium oxide (C1.2.2.1)

C1.2.2
LAW OF DEFINITE PROPORTIONS

C1.2.2.1
Synthesis of magnesium oxide

Cat.-Nr.	Name	C1.2.2.1
666 9881	Combustion boat, glazed	3
664 077	Reaction tube, quartz, 300 x 20 mm dia.	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1
665 913	Gas syringe, 100 ml with 1-way stopcock	1
666 714	Cartridge burner, DIN type	1
666 715	Cartridge	1
300 76	Laboratory stand II	1
666 731	Gas igniter, mechanical	1
667 7988	Analytical balance ABS 80-4, 83:0.0001 g	1
667 194	Silicone tubing, 7 mm diam., 1 m	1
666 4660	Adhesive magnetic board, 300 mm	6
666 4665	Spring clips, magnetic, size 7a, 30...32 mm	4
666 428	Panel frame C100, two-level, for CPS	1
673 1000	Magnesium, ribbon, 25 g	1
674 6970	Hydrochloric acid, 0.5 mol/l, 500 ml	1
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
604 510	Hose connector, 4...15 mm	1

The law of definite proportions is one of the laws of proportion and a fundamental principle in chemistry. It is the basis for the concept of the mol, and stoichiometry would also be unthinkable without this law. Two substances always react with one another in equal (= constant) proportions, which means that there are fixed combination relationships. Developed in part through longsome analyses carried out by Berzelius at the beginning of the 19th century, this law made it possible to write reaction equations for the first time.

In experiment C1.2.2.1, the law of definite proportions is confirmed by the synthesis of magnesium oxide. Magnesium reacts with oxygen in a luminous reaction to magnesium oxide.

$$2\ Mg + O_2 \rightarrow 2\ MgO$$

The starting material magnesium and the product magnesium oxide can be weighed. In addition, the quantity of oxygen consumed is determined by measuring the volume. The results can be used to determine the mass ratio of oxygen to magnesium. Repeated tests can then show that it remains constant.



Analysis of copper(I) oxide and copper(II) oxide (C1.2.3.1_a)

C1.2.3
LAW OF MULTIPLE PROPORTIONS

C1.2.3.1
Analysis of copper(I) oxide and copper(II) oxide

Cat.-Nr.	Name	C1.2.3.1 (a)	C1.2.3.1 (b)
666 428	Panel frame C100, two-level, for CPS	1	
666 4660	Adhesive magnetic board, 300 mm	4	
666 4659	Adhesive magnetic board, 500 mm	1	
666 4662	Spring clips, magnetic, size 3, 11...14 mm	3	
666 4664	Spring clips, magnetic, size 6a, 27...29 mm	1	
666 4795	HydroStik PRO, CPS	1	
666 4798	HydroFill PRO	1	1
664 077	Reaction tube, quartz, 300 x 20 mm dia.	1	1
664 086	U-Tube, 160 mm, 2 side taps, 2 SB 19	1	1
667 312	Glass connector, 2 x GL 18	1	
664 800	Gas scrubber bottle, lower section, 200 ml	1	1
664 806	Glass tube insert with filter, ST 29/32	1	1
667 255	Rubber stopper, solid, 16...21 mm diam.	2	2
667 286	Silicone stopper, one 7-mm hole, 16...21 mm diam.	2	2
667 194	Silicone tubing, 7 mm diam., 1 m	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
604 520	Connector with nipple	1	
665 238	Glass nozzle, 90° angle	1	1
666 988	Combustion boat, not glazed, 80 x 12 mm	2	2
667 035	Crucible tongs, 200 mm	1	1
667 016	Scissors, 200 mm, pointed	1	1
667 034	Tweezers, blunt, 200 mm	1	1
604 5671	Steel double microspatula, 130 mm	1	1
666 968	Spoon-ended spatula, stainless steel, 180 mm	1	1
666 714	Cartridge burner, DIN type	2	2
666 715	Cartridge	2	2

Cat.-Nr.	Name	C1.2.3.1 (a)	C1.2.3.1 (b)
666 724	Wide-flame attachment	2	2
300 76	Laboratory stand II	2	2
665 212ET10	Glass stirring rod, 200 mm x 8 mm diam., set of 10	1	1
664 925	Vacuum dessicator	1	1
667 7988	Analytical balance ABS 80-4, 83:0.0001 g	1	1
666 8036	Drying Oven UNB 30 l	1	1
672 9300	Copper(I)-oxide, 25 g	1	1
672 9500	Copper(II)-oxide, powder, 50 g	1	1
672 7781	Silica gel with indicator, 500 g	1	1
672 1000	Glass wool, 10 g	1	1
671 8400	Iron wool, 50 g	1	1
666 602	Base rail, 55 cm		1
666 615	Universal bosshead		8
666 555	Universal clamp, 0...80 mm		3
666 609ET2	Stand tubes, 450 mm, 10 mm diam. , set of 2		2
666 4796	HydroStik PRO		1
666 4797	Regulating valve		1
604 510	Hose connector, 4...15 mm		1

The law of multiple proportions states that the ratio of the masses of two elements which combine to form different chemical compounds is always a whole number.

Experiment C1.2.3.1 determines the mass ratios of copper and oxygen in copper(I) oxide and copper(II) oxide. In these compounds, the elements copper and oxygen are combined with one another in different mass ratios. Those different ratios can be determined by quantitative reduction with hydrogen.



Electrolytic water decomposition according to Hoffmann (C1.3.1.1)

C1.3.1
WATER DECOMPOSITION

C1.3.1.1
Electrolytic water decomposition according to Hoffmann

Cat.-Nr.	Name	C1.3.1.1
664 350	Water electrolysis unit	1
521 546	DC Power Supply 0 ... 16 V, 0 ... 5 A	1
501 46	Connecting leads, 19 A, 100 cm, red/blue, pair	1
531 836	Universal measuring instrument, Chemistry	1
524 0621	UIP sensor S	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
602 953	Measuring cylinder, Boro 3.3, 100 ml, glass base	1
674 7920	Sulfuric acid, diluted, approx. 2 N, 500 ml	1

Water consists of hydrogen and oxygen, which are bound to one another in the ratio of 2:1. So the formula is H_2O. This formula can be derived from decomposition of water by electrolysis.

In experiment C1.3.1.1, water is analyzed by electrolysis in the Hoffmann voltameter. The transformation of electrical energy into chemical energy is demonstrated at the same time. First the gases generated - hydrogen and oxygen - can be determined qualitatively. Quantitative assessment of the quantities of gas generated can then be used to derive the chemical formula for the compound water.

$$2\,H_2O(l) \rightleftharpoons 2\,H_2\uparrow + O_2\uparrow$$



Qualitative water synthesis (C1.3.2.1_a)

C1.3.2
WATER SYNTHESIS

C1.3.2.1
Qualitative water synthesis

Cat.-Nr.	Name	C1.3.2.1 (a)	C1.3.2.1 (b)
375 56	Water jet pump	1	1
602 024	Beaker, Boro 3.3, 800 ml, squat	1	1
665 001	Funnel for gas collection	1	1
664 800	Gas scrubber bottle, lower section, 200 ml	1	1
664 805	Glass tube insert, ST 29/32	1	
665 237	Glass nozzle, straight	1	1
664 093	U-tube, 160 x 22 mm, 2 side taps	1	1
300 02	Stand base, V-shaped, small	2	
608 051	Stand tube, 750 mm, diam. 10 mm	2	
301 09	Bosshead S	4	
666 555	Universal clamp, 0...80 mm	4	
300 76	Laboratory stand II	1	1
667 257	Rubber stopper, solid, 19...24 mm diam.	2	2
660 997	Minican pressurised gas canister, hydrogen	1	
660 980	Fine regulating valve for minican gas canisters	1	
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1	
604 510	Hose connector, 4...15 mm	1	
667 183	Rubber tubing, 1 m x 8 mm diam., DIN 12865	1	
672 9700	Copper(II)-sulfate, anhydrous, 50 g	1	1
675 3410	Water, pure, 5 l	1	1
671 8400	Iron wool, 50 g	1	1
664 809	Gas scrubber bottle insert, for test tubes		1
666 425	Panel frame C50, two-level, for CPS		1
666 4659	Adhesive magnetic board, 500 mm		1
666 4661	Spring clips, magnetic, size 2, 9...11 mm		1
666 4662	Spring clips, magnetic, size 3, 11...14 mm		1
666 4664	Spring clips, magnetic, size 6a, 27...29 mm		1
667 312	Glass connector, 2 x GL 18		1
666 4795	HydroStik PRO, CPS		1
666 4798	HydroFill PRO		1
667 197	Silicone tubing, 4 mm diam., 1 m		1

Water is available in large quantities on Earth, but it can also be synthesised in the laboratory. The synthesis of water is a complementary experiment to the electrolytic decomposition of water.

In experiment C1.3.2.1, hydrogen is burned. The resulting hydrogen oxide is collected in a U-tube. White copper(II)-sulfate or water detection test paper is used to prove that it is water.

$$2\,H_2 + O_2 \rightleftharpoons 2\,H_2O$$

The experiment can be set up with standard stand rots (variant a) or in a CPS frame (variant b).

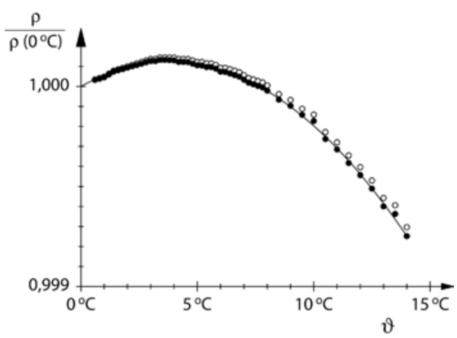


Thermal anomaly of water (C1.3.3.1)

C1.3.3
PROPERTIES OF WATER

C1.3.3.1
Thermal anomaly of water

Cat.-Nr.	Name	C1.3.3.1
667 505	Anomaly of water apparatus	1
666 8451	Magnetic stirrer	1
664 195	Glass tanks	1
665 009	Funnel, PP, 75 mm diam.	1
307 66	Tubing (rubber)	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
666 555	Universal clamp, 0...80 mm	1
301 09	Bosshead S	1
300 02	Stand base, V-shaped, small	1
531 836	Universal measuring instrument, Chemistry	1
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1



Relative density of water as a function of the temperature

Water is necessary for life. This is because of the special properties of water as compared with other substances. Water is one of the few compounds which exists in nature in all three states of matter: solid (ice), liquid (water) and gas (water vapour).

Water has a density anomaly: up to a temperature of 4 °C, water has a negative coefficient of expansion , i.e. it shrinks when warmed. After passing through zero at 4 °C, the coefficient of expansion becomes positive. So the density of water reaches a maximum at 4 °C.

In experiment C1.3.3.1, the density maximum of water is proven by measuring its expansion in a vessel with a riser. Starting from room temperature, the complete setup is cooled down in an ice water bath to about 1 °C under constant stirring, or after cooling in a freezer, it is warmed slowly by the ambient temperature. The level *h*, in a riser with a cross-sectional area A is measured as a function of the water temperature ϑ. Because the change in volume relative to the total volume V_0 is small, the result obtained for density is

$$\rho(\vartheta) = \rho(0\ ^\circ\text{C}) \cdot \left(1 - \frac{A}{V_0} \cdot h(\vartheta)\right).$$



Determination of the oxygen content of air (C1.4.1.1)

C1.4.1
THE COMPONENTS OF AIR

C1.4.1.1
Determination of the oxygen content of air

Cat.-Nr.	Name	C1.4.1.1
664 0771	Reaction tube, quartz, GL 18	1
664 079	Copper wire gauze, roll, 80 x 7.5 mm Ø	1
665 912	Gas syringe, 100 ml	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1
665 936	Immersion tube manometer, after Schiele	1
666 714	Cartridge burner, DIN type	1
666 724	Wide-flame attachment	1
300 76	Laboratory stand II	1
666 4660	Adhesive magnetic board, 300 mm	6
666 4665	Spring clips, magnetic, size 7a, 30...32 mm	5
666 428	Panel frame C100, two-level, for CPS	1
667 312	Glass connector, 2 x GL 18	1

Air is a mixture of different gases. It essentially comprises nitrogen (78 %), oxygen (21 %), noble gases (1 %) and carbon dioxide (0.04 %). It also contains trace quantities of other gases. The component which is vital to us, oxygen, also participates in important reactions, e.g. in combustion and corrosion.

Experiment C1.4.1.1 determines the oxygen content of air. The determination of the oxygen content uses the fact that certain substances can react quantitatively with oxygen to form oxides. For this purpose, the oxygen of a defined volume of air is reacted with copper and removed from the gas space as copper oxide.

$$2\ Cu + O_2 \rightarrow 2\ CuO$$

From the resulting reduction in volume, the oxygen content of the original air can be easily calculated in per cent by volume. The gas remaining in the apparatus can be studied further: One can find out that it does not sustain combustion.



Determination of the density of air (C1.4.1.2)

C1.4.1
THE COMPONENTS OF AIR

C1.4.1.2
Determination of the density of air

Cat.-Nr.	Name	C1.4.1.2
379 07	Sphere with 2 stop-cocks, glass	1
667 072	Support ring for 250-ml round flask, cork	1
315 05	Single-pan suspension balance 311	1
375 58	Hand vacuum pump	1
661 082	Stopcock grease, 60 g	1

In experiment C1.4.1.2, a sphere of known volume with two stopcocks is used to determine the density of air. The mass of the enclosed air is determined from the measured difference between the total weight of the sphere filled with air and the empty weight of the evacuated sphere.



Production of gases with a Kipp's apparatus (C1.4.2.1)

C1.4.2
PRODUCTION OF GASES

C1.4.2.1
Production of gases with a Kipp's apparatus

C1.4.2.2
Production of gases with a dropping funnel

Cat.-Nr.	Name	C1.4.2.1	C1.4.2.2
665 647	Maey gas generator	1	1
666 6221	Experimental tray	1	1
666 623	Angle strip	1	1
301 01	Leybold multiclamp	3	3
301 27	Stand rod, 50 cm, 10 mm diam.	3	3
301 09	Bosshead S	4	4
666 555	Universal clamp, 0...80 mm	4	4
604 501	PVC tube, 7 mm diam., 1 m	1	1
664 800	Gas scrubber bottle, lower section, 200 ml	2	2
664 805	Glass tube insert, ST 29/32	2	2
665 914	Gas syringe, 100 ml with 3-way stopcock	1	1
675 4800	Zinc, granulated, 100 g	1	
674 6920	Hydrochloric acid, approx. 2 mol/l, 500ml	1	
665 649	Dropper funnel, 75 ml, 2 NS 29/32		1
673 2200	Manganese(IV)-oxide, 100 g		1
675 3500	Hydrogen peroxide, 30 %, 250 ml		1

By reacting different chemicals, in most cases a liquid and a solid material, many different gases can be generated. The gases generated can then be used and studied in other experiments.

To purify the gases generated, wash bottles with H_2SO_4 as a desiccator, for example, can be added downstream. Appropriate reagents can also be used to demonstrate assay reactions.

Experiment C1.4.2.1 uses the gas generator according to Maey, the principle of which corresponds to that of the Kipp's apparatus for the production of hydrogen: zinc granules are added to a setup with frits. Diluted hydrochloric acid is added to the flask, which passes through the frits to reach the zinc. Hydrogen is generated there.

$$Zn + 2\,H^+ \rightarrow Zn^{2+} + H_2$$

Other gases which can be generated in a similar way include: CO_2, H_2S and NO.

In experiment C1.4.2.2, a dropping funnel is used and the solid is introduced into the flask. The reaction is controlled here by adding drops of a liquid and the gas can be drawn off via the stopcock on the side. In the production of oxygen, for example, hydrogen peroxide is dripped onto the catalyst manganese dioxide and decomposes into water and oxygen.

$$2\,H_2O_2 \xrightarrow{MnO} 2\,H_2O + O_2$$

This variant can be used to produce several other gases, including: O_2, NH_3, Cl_2, HCl, SO_2, NO_2, CO, C_2H_2 and CH_4.



Hydrogen as a reducing agent (C1.4.3.1)

C1.4.3
REACTIONS WITH GASES

C1.4.3.1
Hydrogen as a reducing agent

Cat.-Nr.	Name	C1.4.3.1
664 0772	Reaction tube, quartz, 16 cm	1
667 286	Silicone stopper, one 7-mm hole, 16...21 mm diam.	2
666 988	Combustion boat, not glazed, 80 x 12 mm	1
665 201	Glass tubes, 80 mm x 8mm diam., set of 10	1
665 238	Glass nozzle, 90° angle	1
666 714	Cartridge burner, DIN type	1
666 724	Wide-flame attachment	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
667 198	Silicone tubing, 2 mm diam., 1 m	1
666 602	Base rail, 55 cm	1
666 605	Stand tube, 50 mm, 13 mm diam.	2
666 615	Universal bosshead	3
301 09	Bosshead S	3
666 555	Universal clamp, 0...80 mm	2
667 7988	Analytical balance ABS 80-4, 83:0.0001 g	1
602 421	Gas-washing bottle, complete, with ST, with filter, 250 ml	1
604 5672	Double microspatula, steel, 150 mm	1
666 4796	HydroStik PRO	1
666 4797	Regulating valve	1
666 4798	HydroFill PRO	1
672 9500	Copper(II)-oxide, powder, 50 g	1
671 8400	Iron wool, 50 g	1
674 7860	Sulfuric acid, 95-98 %, 500 ml	1

Gases, too, can participate in chemical reactions. In most cases they are added in surplus and their properties enable complete penetration of the reaction space. Reactions with gases are easy to follow because the volume at constant pressure allows a simple determination of the quantity of material.

In experiment C1.4.3.1, copper oxide is reduced with hydrogen to form elementary copper. Hydrogen is a good reducing agent. Its ability to react applies not only to free oxygen but also to oxygen compounds. The metal is formed in this way when transforming a metal oxide (as in this experiment) with hydrogen.



Extraction of copper from copper oxide (C1.5.1.1)

C1.5.1
EXTRACTION OF METALS

C1.5.1.1
Extraction of copper from copper oxide

Cat.-Nr.	Name	C1.5.1.1
667 092	Mortar, porcelain, 70 mm Ø	1
608 360	Pestle, 52 mm long	1
666 502	Bunsen burner stand, 450 mm high	1
301 09	Bosshead S	1
666 555	Universal clamp, 0...80 mm	1
667 050	Test tube rack, plastic, for 9 tubes, 18 mm diam.	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 254	Rubber stopper, one 7-mm hole, 17...23 mm diam.	1
667 253	Rubber stopper, solid, 14...18 mm diam.	1
667 027	Tweezers, blunt, 130 mm	1
665 231	Angled tube, 90°, 250/50 mm	1
664 101	Beaker, DURAN, 100 ml, squat	1
666 962	Double-ended spatula, stainless steel, 150 mm	1
656 017	Teclu burner, universal	1
666 729	Safety gas hose, 1 m	1
672 9500	Copper(II)-oxide, powder, 50 g	1
672 2490	Charcoal, small pieces, 500 g	1
672 1010	Glass wool, 100 g	1
671 2900	Calcium hydroxide, 50 g	1

Most of the ores found in nature are oxides and sulphides: e.g. magnetite (lodestone, Fe_3O_4), haematite (red iron oxide, Fe_2O_3), cassiterite (SnO_2), tenorite (CuO), cuprite (Cu_2O), pyrite (fool's gold, FeS_2) and sphalerite (ZnS). Reduction can be used to extract metals from oxide ores and from the metal oxides formed during the metallurgical process known as "roasting".

In experiment C1.5.1.1, charcoal is the reducing agent to reduce tenorite (CuO) to elementary copper. When heated, the mixture of tenorite and pulverised charcoal produces red copper and carbon dioxide. A saturated calcium hydroxide solution is used to verify the presence of the carbon dioxide.



Conditions for iron corrosion (C1.5.3.1)

C1.5.3
CORROSION

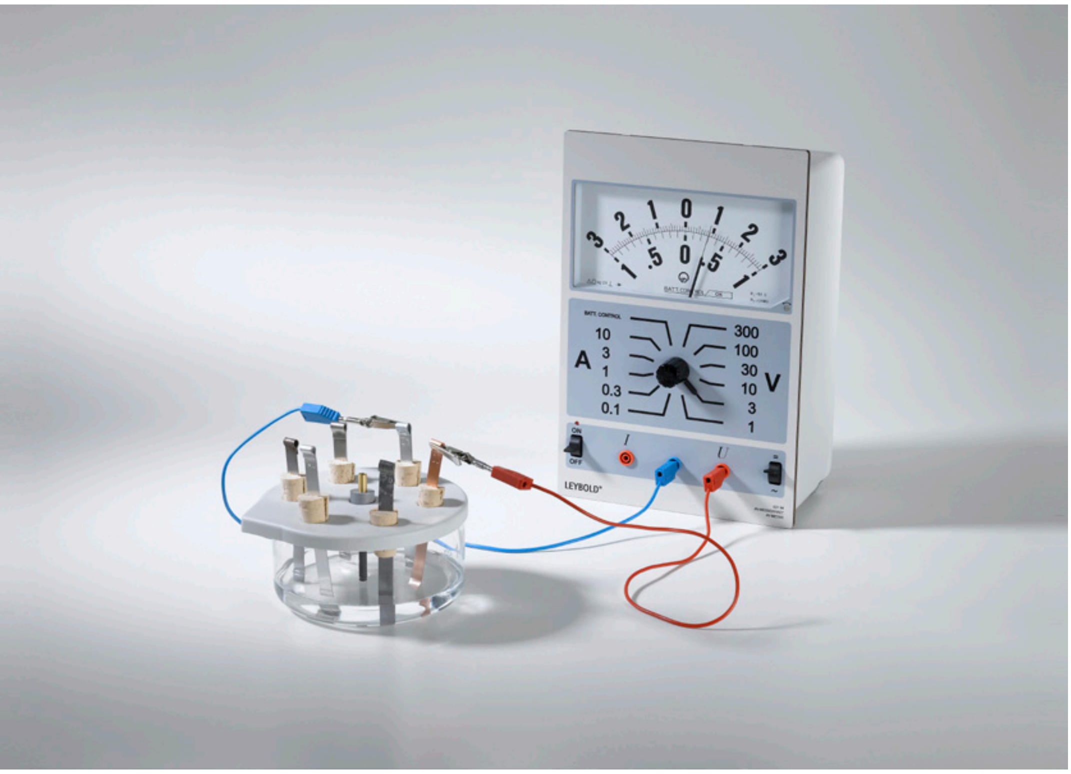
C1.5.3.1
Conditions for iron corrosion

Cat.-Nr.	Name	C1.5.3.1
665 936	Immersion tube manometer, after Schiele	1
667 054	Test tube rack, for 12 tubes, 32 mm diam.	1
664 045	Test tubes, Fiolax, 30 x 200 mm, set of 10	1
665 232	Angled tube, 90°, 50/50 mm	1
667 261	Rubber stopper, one 7-mm hole, 25-31 mm diam.	1
667 180	Rubber tubing, 1 m x 7 mm diam., DIN 12865	1
300 02	Stand base, V-shaped, small	2
301 28ET2	Stand rod, 45 cm, 10 mm diam., set of 2	1
301 09	Bosshead S	2
666 555	Universal clamp, 0...80 mm	2
664 183	Petri dishes	1
667 0344	Tweezer, blunt, 145 mm	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
666 962	Double-ended spatula, stainless steel, 150 mm	1
671 8400	Iron wool, 50 g	1
670 8200	Petroleum ether, 90...110 °C, 250 ml	1
309 42	Colouring, red, 10 g	1

The term "corrosion" refers to the slow oxidation of metal surfaces under the influence of the surrounding medium. Corrosion (rust) destroys large quantities of iron and steel. Corrosion protection (rust protection) is an extremely important topic in the metal industry.

Experiment C1.5.3.1 examines the conditions under which ferrous metals corrode. Wads of iron wool are subjected to different conditions. In one test tube, boiled water is poured over the iron wool, in the second test tube the iron wool is left dry, and the third test tube is rinsed with tap water so that droplets remain in the tube. This test tube is connected to an immersion tube manometer filled with coloured water. The changes in the iron wool and the changes in the immersion tube manometer are observed. It can be seen that under the simultaneous action of water and oxygen on iron, corrosion forms and a measurable negative pressure builds up in the apparatus.

$$4\,Fe + 2\,H_2O + 3\,O_2 \rightarrow 4\,FeO(OH)$$



Experiments with the corrosion set (C1.5.3.2)

C1.5.3
CORROSION

C1.5.3.2
Experiments with the corrosion set

C1.5.3.3
Electrochemical corrosion protection

Cat.-Nr.	Name	C1.5.3.2	C1.5.3.3
664 356	Corrosion set	1	
531 94	AV meter	1	
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1	
501 861	Crocodile-clips, polished, set of 6	1	
664 391ET4	Grindstones, set of 4	1	
674 7920	Sulfuric acid, diluted, approx. 2 N, 500 ml	1	
664 4071	Electrochemistry demonstration unit, CPS		1
301 339	Stand bases, pair		1
664 401	Electrochemistry accessories set		1
667 7967	Compact Balance EMB200-2		1
665 009	Funnel, PP, 75 mm diam.		1
664 131	Beaker, Boro3.3, 400 ml, squat		1
602 022	Beaker, Boro 3.3, 100 ml, squat		1
665 754	Measuring cylinder, 100 ml, with plastic base		1
666 967	Spoon-ended spatula, stainless steel, 150 mm		1
673 5700	Sodium chloride, 250 g		1
672 6100	Potassium ferrocyanide (III), 50 g		1
674 2410	Phenolphthaleine, 50 g		1
673 1000	Magnesium, ribbon, 25 g		1

Experiment C1.5.3.2 demonstrates that every type of corrosion has its origin in chemical and electrochemical processes. Different metals generate an electric voltage when they are immersed in an electrically conductive medium at the same time, such as diluted sulfuric acid. The further apart the metals are in the electrochemical series the higher that voltage.

In experiment C1.5.3.3, the cathodic protection anode technique is used to prevent electrochemical corrosion. The method is based on the fact that the speed of electrochemical corrosion processes depends on the electrode potential. If that electrode potential is shifted externally, the corrosion can be inhibited or greatly restricted. In the experiment, a zinc electrode is used as a cathodic protection anode. The metal to be protected is conductively connected to a less noble metal; a corrosion element is formed in which the less noble metal (the cathodic protection anode) dissolves while the nobler metal remains protected.





C1.6.2
THE OXYGEN FAMILY

C1.6.2.1
Change of modification of sulfur

Change of modification of sulfur (C1.6.2.1)

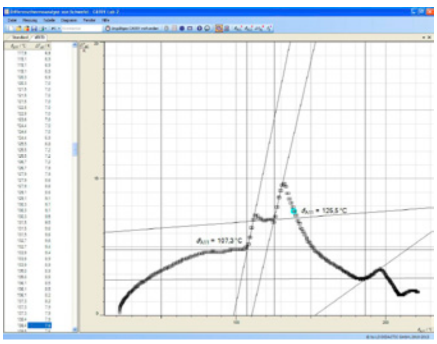
Cat.-Nr.	Name	C1.6.2.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	2
666 202	Heating block with 2 holes	1
666 203	Set of 20 glass tubes	1
666 8471	Magnetic stirrer with hotplate	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
301 09	Bosshead S	2
666 555	Universal clamp, 0...80 mm	2
666 960	Powder spatula, stainless steel, 150 mm	1
667 092	Mortar, porcelain, 70 mm Ø	1
608 360	Pestle, 52 mm long	1
674 7610	Sulfur, sublimed, 500 g	1
670 2900	Aluminium oxide, 250 g	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The oxygen family is the 6th main group in the periodic table. Its elements are also known as "chalcogens", i.e. ore generators. They include the non-metals oxygen and sulfur, the metalloids selenium and tellurium, and the metal polonium.

The elements of this group must acquire two electrons in order to achieve noble gas configuration. Alternatively, they can form two covalent bonds.

Experiment C1.6.2.1 takes a closer look at sulfur. Sulfur has the ability to form chains and rings, and that makes it the element with the most modifications. Those modification changes are studied by differential thermal analysis. For this purpose, a sample of sulfur is heated and its temperature is measured. During the modification changes, the temperature of the sample no longer increases as compared with a control substance. There is no measurable temperature increase until the modification change is complete.



Observing the change of modification of sulfur





C1.7.2
ACID STRENGTHS AND pH VALUES

C1.7.2.1
Determination of acidity (pKa value) by titration

Determination of acidity (pKa value) by titration (C1.7.2.1)

Cat.-Nr.	Name	C1.7.2.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
607 105	Magnetic stirrer mini	1
665 845	Burette, clear glass, 25 ml	1
666 559	Burette clamp for 1 burette, roller clamp	1
665 816	Burette filling funnel, plastic, 25 mm diam.	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 26	Stand rod, 25 cm, 10 mm diam.	1
300 11	Saddle base	1
301 09	Bosshead S	1
666 555	Universal clamp, 0...80 mm	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
661 243	Wash bottle, PE, 500 ml	1
673 8421	Soda lye, 1 mol/l, 1 l	1
671 9560	Acetic acid, 0.1 mol/l, 500 ml	1
673 8410	Soda lye, 0.1 mol/l, 500 ml	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The acidity or alkalinity of a solution is expressed by the pH value. It is the negative logarithm to the base 10 of the hydrogen ion concentration. pH values below 7 are acidic, and pH values above 7 are basic. The pH plays a decisive role in the course of many chemical and biochemical processes, where it normally ranges between 4 and 9.

In experiment C1.7.2.1, the acidity (pK_a value) of acetic acid is determined. Between an acid HA and its base A^- the following equilibrium reaction takes place in an aqueous solution :

$$HA^+ + H_2O \rightleftharpoons H_3O^+ + A^-$$

According to the law of mass action, the equilibrium position is described by the equilibrium constant K_a:

$$K = \frac{[H_3O^+]\cdot[A^-]}{[HA]\cdot[H_2O]}; K_a = K\cdot[H_2O] = \frac{[H_3O^+]\cdot[A^-]}{[HA]}$$

By analogy to the pH value, the pK_a value is given as the negative base 10 logarithm of the numerical value of K_a

$$pK_a = -\lg\frac{[H_3O^+]\times[A^-]}{[HA]}$$

The lower the value of pK_a, the higher the acidity. The pK_a value is numerically equal to the pH value of a solution when the protonated and non-protonated forms are present in equal concentration.





C1.7.2
ACID STRENGTHS AND pH VALUES

C1.7.2.2
Analysis of triprotic phosphoric acid by titration

Analysis of triprotic phosphoric acid by titration (C1.7.2.2)

Cat.-Nr.	Name	C1.7.2.2
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
524 074	Timer S	1
337 4681	Drop counter	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	2
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
665 845	Burette, clear glass, 25 ml	1
665 816	Burette filling funnel, plastic, 25 mm diam.	1
666 559	Burette clamp for 1 burette, roller clamp	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
300 11	Saddle base	1
301 26	Stand rod, 25 cm, 10 mm diam.	1
301 09	Bosshead S	2
666 555	Universal clamp, 0...80 mm	2
674 3440	Phosphoric acid, 10 %, 100 ml	1
672 4460	Potassium lye, 1 N (1 mol/l), 1 l	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
674 2500	Phenolphthaleine solution, 100 ml	1*
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The acidity or alkalinity of a solution is expressed by the pH value. It is the negative logarithm to the base 10 of the hydrogen ion concentration. pH values below 7 are acidic, and pH values above 7 are basic. The pH plays a decisive role in the course of many chemical and biochemical processes, where it normally ranges between 4 and 9.

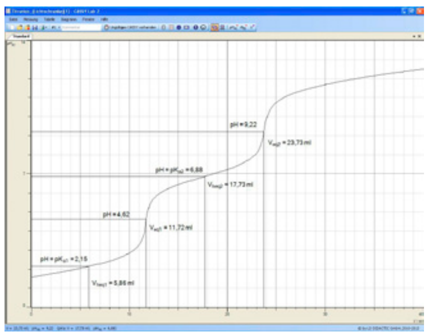
Phosphoric acid is a triprotic acid. When dissolved in water, it first gives up one proton and dissociates to dihydrogen phosphate, i.e. it reacts like a monoprotic acid (see formula 1). The addition of sodium hydroxide, e.g. during titration, first leads to complete dissociation of the phosphoric acid into dihydrogen phosphate.

The second protolysis, i.e. the reaction to hydrogen phosphate (see formula 2), occurs only after a high pH value has been reached, approx. pH 9. The third protolysis requires a considerably higher pH value (see formula 3). In experiment C1.7.2.2, the first two protolysis steps of phosphoric acid are determined in an automatic titration.

1: $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+$

2: $H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+$

3: $HPO_4^{2-} + H_2O \rightleftharpoons PO_4^{3-} + H_3O^+$



Titration curve of the triprotic acid phosphoric acid





C1.7.3
SALTS AND IONIC COMPOUNDS

C1.7.3.1
Determination of the enthalpy of solution of salts

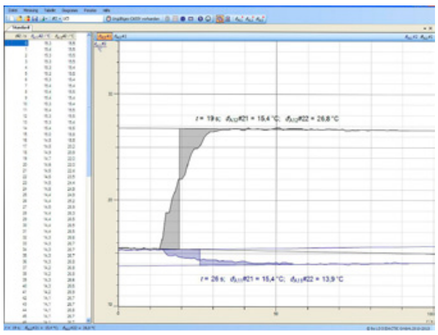
Determination of the enthalpy of solution of salts (C1.7.3.1)

Cat.-Nr.	Name	C1.7.3.1
386 40	Dewar flask, clear, for demonstration	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1
524 0031	Bluetooth dongle	1
524 220	CASSY Lab 2	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
524 0673	NiCr-Ni adapter S, type K	1
664 155	Watch glass dish, 100 mm diam.	1
607 105	Magnetic stirrer mini	1
300 11	Saddle base	1
301 26	Stand rod, 25 cm, 10 mm diam.	1
301 09	Bosshead S	1
602 953	Measuring cylinder, Boro 3.3, 100 ml, glass base	1
667 7977	Electronic Balance 200 : 0,01	1
666 968	Spoon-ended spatula, stainless steel, 180 mm	1
673 0510	Lithium chloride, 100 g	1
672 5210	Potassium chloride, 250 g	1
673 5710	Sodium chloride, 500 g	1
	additionally required: PC with Windows XP/Vista/7/8	

Salts are chemical compounds made of ions. The positively charged cation is often a metal and the negatively charged anion is often a non-metal, as in the case of sodium chloride (table salt). In polar solvents such as water, salts dissolve forming hydrated ions.

When a salt is dissolved in water, it can heat the solution up or cool it down. Accordingly, the enthalpy of solution is either negative (heat generating) or positive (heat absorbing). For the dissolution of the crystal, the so-called lattice energy must be applied. In hydration, on the other hand, energy is released. Enthalpies of solution cannot be calculated with certainty, but rather must be determined experimentally.

Experiment C1.7.3.1 determines the enthalpy of solution of various chloride salts. For this purpose, the salts LiCl, KCl and NaCl are dissolved in the transparent demonstration Dewar flask. The enthalpy of solution can then be calculated from the temperature change.



The enthalpy of solution of different salts



Determination of the solubility product of silver halides (C1.7.3.2)

C1.7.3
SALTS AND IONIC COMPOUNDS

C1.7.3.2
Determination of the solubility product of silver halides

Cat.-Nr.	Name	C1.7.3.2
531 836	Universal measuring instrument, Chemistry	1
524 0621	UIP sensor S	1
664 137	Beaker, Boro3.3, 100 ml, tall	5
665 754	Measuring cylinder, 100 ml, with plastic base	1
667 455	Salt bridge, 90 mm x 90 mm, 20 mm diam.	1
667 255	Rubber stopper, solid, 16...21 mm diam.	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
664 421	Plate electrodes, silver, 55 x 40 mm, set of 2	1
501 861	Crocodile-clips, polished, set of 6	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
667 7977	Electronic Balance 200 : 0,01	1
300 11	Saddle base	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp, 0...80 mm	1
665 953	Droppers, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs.	1
665 009	Funnel, PP, 75 mm diam.	1
674 8800	Silver nitrate solution, 0,1 mol/l, 250 ml	1
670 3600	Ammonia solution, 25 %, 250 ml	1
673 5740	Sodium chloride solution, approx. 1 M, 500 ml	1
672 4930	Potassium bromide solution, 250 ml	1
672 6620	Potassium iodide, 50 g	1
672 6800	Potassium nitrate, 100 g	1

In experiment C1.7.3.2, the solubility product of silver salts is determined. The solubility product is the product of the concentrations of cations and anions of an electrolyte in a saturated aqueous solution at constant temperature. In a saturated salt solution, a chemical equilibrium exists between the solid and the solution, i.e. just as many ions leave the ion lattice per unit time as enter it in the opposite sense. Using voltage measurements and the Nernst equation, the solubility products of the low solubility salts AgCl, AgBr and AgI are determined.

C2 ORGANIC CHEMISTRY



Quantitative determination of carbon (C2.1.1.1)

C2.1.1
COMPOSITION OF ORGANIC COMPOUNDS

C2.1.1.1
Quantitative determination of carbon

C2.1.1.2
Quantitative determination of hydrogen

Cat.-Nr.	Name	C2.1.1.1	C2.1.1.2
664 069	Reaction tube, quartz, 220 x 25 mm Ø, for butane combustion	1	1
665 374	Drying tube, 1 GL 18 and 1 GL 25, 120 mm x 30 mm diam.	2	2
665 912	Gas syringe, 100 ml	1	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1	1
665 918	Gas syringe holder	1	1
656 017	Teclu burner, universal	1	1
666 724	Wide-flame attachment	1	1
666 729	Safety gas hose, 1 m	1	1
666 603	Base rail, 95 cm	1	1
666 609ET2	Stand tubes, 450 mm, 10 mm diam. , set of 2	2	2
666 615	Universal bosshead	4	4
301 09	Bosshead S	5	5
666 555	Universal clamp, 0...80 mm	3	3
301 72	Universal clamp, 0...120 mm	1	1
666 962	Double-ended spatula, stainless steel, 150 mm	1	1
665 994	Graduated pipette, 1 ml	1	1
666 003	Pipetting ball	1	1
667 180	Rubber tubing, 1 m x 7 mm diam., DIN 12865	1	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1	1
604 510	Hose connector, 4...15 mm	1	1
661 000	Minican pressurised gas canister, nitrogen	1	1
660 989	Minican pressurised gas canister, n-Butane	1	1
660 980	Fine regulating valve for minican gas canisters	1	1
667 034	Tweezers, blunt, 200 mm	1	1
672 9410	Copper oxide, wire form, 250 g	1	1

Cat.-Nr.	Name	C2.1.1.1	C2.1.1.2
671 2410	Calcium chloride, granulated, 250 g	1	1
674 4310	1-Propanol, 250 ml	1	1
672 1010	Glass wool, 100 g	1	1
667 605	Safety screen		1
OHS PU123	Electronic precision balance SPU123		1

In order to determine the chemical composition of organic compounds, a quantitative elementary analysis is conducted. Combustion analysis is also still used today for the determination of carbon and hydrogen.

In experiment C2.1.1.1, the carbon content of an organic compound is determined quantitatively. In a combustion analysis, the substance is passed over glowing copper(II) oxide at approx. 800 °C - 900 °C. The carbon is converted to CO_2 and the hydrogen is converted to H_2O. The CO_2 gas generated is collected in a gas syringe and the volume is measured.

In experiment C2.1.1.2, the hydrogen content of an organic compound is determined quantitatively. Here, too, the combustion analysis is carried out, whereby the carbon is converted to CO_2 and the hydrogen is converted to H_2O. The water content is determined from the difference in the weight of the drying tube, and the share of hydrogen is determined from the water content.



Thermal analysis of hydrocarbons (C2.1.2.1)

C2.1.2
HYDROCARBONS

C2.1.2.1
Thermal analysis of hydrocarbons

Cat.-Nr.	Name	C2.1.2.1
666 428	Panel frame C100, two-level, for CPS	1
666 460	Combustion chamber with incandescent wire, CPS	1
666 4660	Adhesive magnetic board, 300 mm	2
666 4664	Spring clips, magnetic, size 6a, 27...29 mm	4
665 914	Gas syringe, 100 ml with 3-way stopcock	2
666 4659	Adhesive magnetic board, 500 mm	1
726 21	Equipment platform, 350 mm	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
521 55	High current power supply	1
660 987	Minican pressurised gas canister, methane	1
660 988	Minican pressurised gas canister, ethane	1
660 980	Fine regulating valve for minican gas canisters	1
667 194	Silicone tubing, 7 mm diam., 1 m	1
604 510	Hose connector, 4...15 mm	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
664 042	Test tubes, Fiolax, 16 x 160 mm, set of 100	1
667 052	Test tube rack, for 12 tubes, 18 mm diam., 6 drying pegs	1
656 016	Bunsen burner, universal	1
666 729	Safety gas hose, 1 m	1
667 605	Safety screen	1

Hydrocarbons are compounds which contain only carbon and hydrogen. A differentiation is made between alkanes, alkenes and alkynes. Alkanes are saturated hydrocarbons. Each C atom forms four single bonds. Unsaturated hydrocarbon compounds have multiple bonds. Alkenes have at least one double bond, alkynes one triple bond. Hydrocarbons can occur in short or long chains. Open chains or branches are found, and they can also comprise ring-shaped molecules.

In order to determine the number of hydrogen atoms as compared with the number of carbon atoms, hydrocarbons can be separated into their elements by thermal decomposition. With gaseous hydrocarbons, this can be done with a filament in a combustion chamber. There the gas is split into hydrogen and carbon black (soot). The ratio of hydrogen to carbon in the compound can be derived directly from the increase in gas volume. In experiment C2.1.2.1, the gases methane and ethane are studied in this way.



Oxidation of propanol (C2.2.2.1)

C2.2.2
OXIDATION REACTIONS

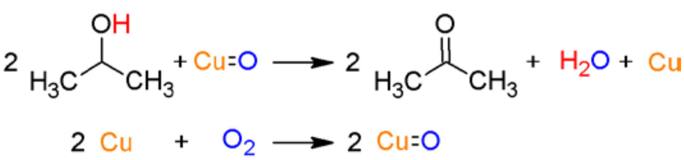
C2.2.2.1
Oxidation of propanol

Cat.-Nr.	Name	C2.2.2.1
666 602	Base rail, 55 cm	1
664 0771	Reaction tube, quartz, GL 18	1
664 078	Copper wire, gauze roll, 60 x 10 mm diam.	1
667 313	Glass connector, 1 GL 18, with glass olive	2
665 935	Spring pressure gauge	1
667 312	Glass connector, 2 x GL 18	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
375 56	Water jet pump	1
666 555	Universal clamp, 0...80 mm	2
301 09	Bosshead S	2
666 615	Universal bosshead	2
666 609ET2	Stand tubes, 450 mm, 10 mm diam. , set of 2	1
664 051	Test tube, with side arm, Boro 3.3, 20 x 180 mm, SB 19	2
667 256	Rubber stopper, one 7-mm hole, 16...21 mm diam.	2
665 231	Angled tube, 90°, 250/50 mm	2
666 714	Cartridge burner, DIN type	1
666 724	Wide-flame attachment	1
664 114	Beaker, DURAN, 400 ml, tall	2
300 76	Laboratory stand II	1
666 963	Spoon-ended spatula, stainless steel, 120 mm	1
664 442	Evaporating dish, 80 mm diam.	1
667 035	Crucible tongs, 200 mm	1
666 685	Wire gauze, 160 mm x 160 mm	1
661 083ET20	Wooden turnings, 200 pcs	1
667 026	Tweezers, pointed, 130 mm	1
667 605	Safety screen	1

Cat.-Nr.	Name	C2.2.2.1
672 1010	Glass wool, 100 g	1
672 1210	Glycerine, 99 %, 250 ml	1
674 4400	2-Propanol, 250 ml	1
672 9710	Copper(II)-sulfate, anhydrous, 250 g	1
	additionally required: cold water, ice, hot water (60 °C)	

Oxidation and reduction reactions also occur in organic chemistry. These involve oxygen transfer reactions, e.g. the oxidation of alcohols to carboxylic acids, or hydrogen transfer reactions, in which, technically, a hydride ion (H^-) is transferred. But redox reactions can also occur radically or via displacement or addition-elimination mechanisms.

In experiment C2.2.2.1, acetone is produced. To do so, the secondary alcohol 2-propanol is oxidised to 2-propanone (acetone). The oxidising agent used is copper oxide (CuO), which at high temperature gives off oxygen to reducing materials. Continuous air supply immediately re-oxidises the metal copper, however. In order to provide the largest possible Cu-CuO surface area, an anoxidised, rolled up copper mesh is used.



Oxidation of propanol and reoxidation of copper to copper oxide



The calorific value of coal (C2.3.1.1)



C2.3.1
ORGANIC COMPOUNDS AS FUELS

C2.3.1.1
The calorific value of coal

C2.3.1.3
The calorific value of fuel oil

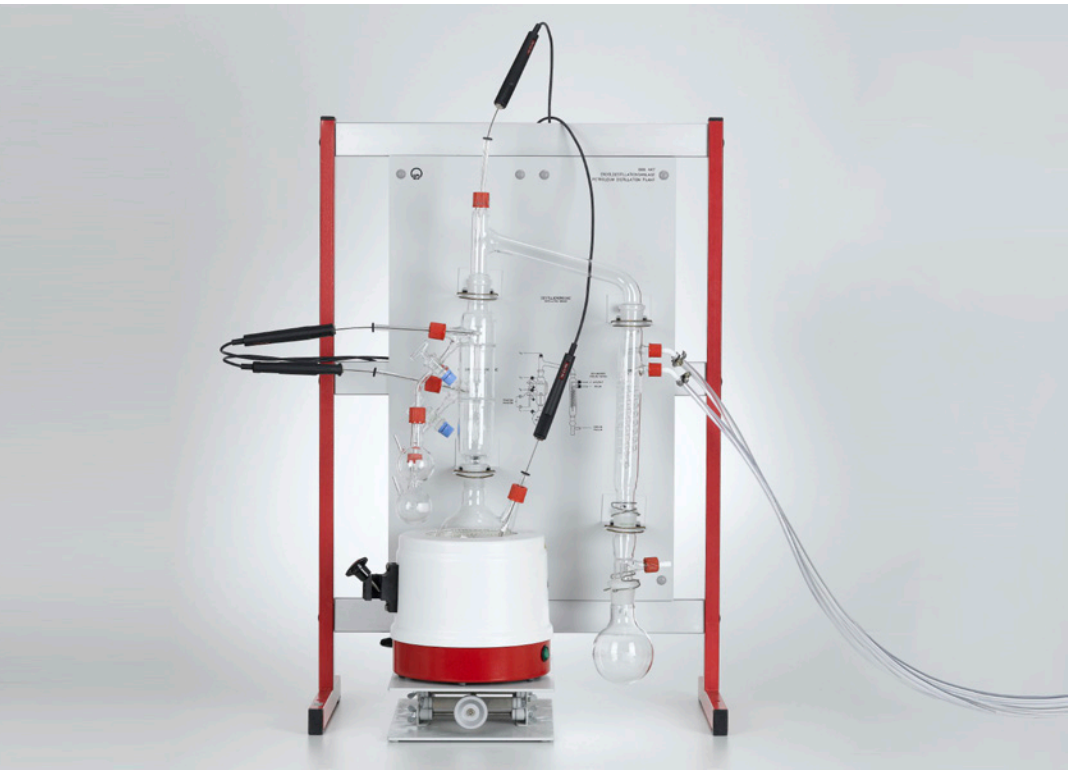
Cat.-Nr.	Name	C2.3.1.1	C2.3.1.3
666 429	Calorimeter for solids and liquids, CPS	1	1
666 819	Stirring top, with GL 32 screw thread	1	1
664 800	Gas scrubber bottle, lower section, 200 ml	4	4
664 805	Glass tube insert, ST 29/32	4	4
521 231	Low-voltage power supply, 3/6/9/12 V	1	1
524 018	Pocket-CASSY 2 Bluetooth	1	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*	1*
524 0031	Bluetooth dongle	1*	1*
524 220	CASSY Lab 2	1	1
524 0673	NiCr-Ni adapter S, type K	1	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1	1
667 312	Glass connector, 2 x GL 18	3	3
667 194	Silicone tubing, 7 mm diam., 1 m	2	2
604 510	Hose connector, 4...15 mm	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
521 546	DC Power Supply 0 ... 16 V, 0 ... 5 A	1	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	2	2
667 7977	Electronic Balance 200 : 0,01	1	1
660 998	Minican pressurised gas canister, oxygen	1	1
660 980	Fine regulating valve for minican gas canisters	1	1
666 4660	Adhesive magnetic board, 300 mm	2	2
666 428	Panel frame C100, two-level, for CPS	1	1
666 4664	Spring clips, magnetic, size 6a, 27...29 mm	4	4
301 312	Console	1	1
726 22	Equipment platform, 500 mm	1	1
	additionally required: PC with Windows XP/Vista/7/8		1

* additionally recommended

Organic compounds store chemical energy. During combustion, the conversion to thermal energy takes place, which is given off to the surroundings in the form of heat. A heating value can be established for every fuel. The heating value of different fuels varies over a wide range. It indicates how much heat is released when one kilogram or one litre or 1 cubic meter of a material is completely burned.

In experiment C2.3.1.1, coal is burned and the heat of combustion is determined with a calorimeter. The calorimeter completely surrounds the sides and top of the combustion chamber. The hot combustion gases generated are fed through a double glass coil and give off their energy to the environment (the glass element and the bath liquid) in the form of heat. In this way, the heat of combustion can be determined using the total heat capacity of the calorimeter.

In experiment C2.3.1.3 the heating value of fuel oil is determined with a demonstration calorimeter.





C2.3.2
FROM CRUDE OIL TO PETROLEUM PRODUCT

C2.3.2.1
Fractionated petroleum distillation with a bubble tray column

Fractionated petroleum distillation with a bubble tray column (C2.3.2.1)

Cat.-Nr.	Name	C2.3.2.1
666 447	Crude oil distillation, bubble tray column, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0673	NiCr-Ni adapter S, type K	2
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	4
666 6533	Heating mantle, 500 ml, adjustable	1
300 75	Laboratory stand I	1
666 659	Clamp for heating mantle	1
666 194	Protective sleeves for temperature sensors, set of 5	1
665 755	Measuring cylinder, 250 ml, with plastic base	1
604 501	PVC tube, 7 mm diam., 1 m	3
604 460	Hose clamp, 8...12 mm	3
664 241	Erlenmeyer flask, 100 ml, narrow neck, SB 19	3
667 281	Assorted cork stoppers, set of 100	3
661 0771	Warning labels, GHS	1
661 081	Aluminium, foil, 1 roll	1
667 026	Tweezers, pointed, 130 mm	1
608 311	Evaporating dish, 72 ml, 77 mm diam.	3
667 605	Safety screen	1
661 083ET20	Wooden turnings, 200 pcs	1
674 5840	Crude oil, artificial, 1 L	1
674 5810	Crude oil, 500 ml	1*
661 091	Boiling stones	1
661 082	Stopcock grease, 60 g	1
672 1200	Glycerine, 99 %, 100 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The organic chemical industry is largely based on the raw materials crude oil and natural gas. Those raw materials were formed a long time ago from biomass through biochemical and geochemical processes. Based on its origin, crude oil is classified as a fossil fuel together with natural gas and coal.

These fuels and raw materials cannot be used directly in their natural condition. First they must be refined by various physical and chemical processes. This is done in so-called oil refineries, where different processes are used in order to produce from the crude oil the desired mineral oil products and primary chemicals for the chemical industry.

Crude oil is first separated into different fractions by fractionated distillation. Individual substances cannot be isolated in this way, because the boiling points are very close to one another. Rather, the objective here is to collect hydrocarbons of certain boiling point ranges.

In chemical engineering, crude oil is distilled in bubble tray columns. This process is simulated in experiment C2.3.2.1. The system is fitted with two bubble trays so multiple fractions can be extracted simultaneously.



Catalytic cracking (C2.3.2.3)

C2.3.2
FROM CRUDE OIL TO PETROLEUM PRODUCT

C2.3.2.3
Catalytic cracking

Cat.-Nr.	Name	C2.3.2.3
665 338	Distillation bridge after Claisen	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
664 300	Round-bottom flask, 100 ml, ST 19/26	1
664 105	Beaker, DURAN, 600 ml, squat	1
667 072	Support ring for round flask, 250 ml, cork	1
665 391ET10	Joint clip, plastic, ST 19/26, set of 10	1
665 237	Glass nozzle, straight	1
665 255	Three-way valve, T-shaped, ST nozzles	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1
667 256	Rubber stopper, one 7-mm hole, 16...21 mm diam.	1
666 161	Chemical thermometer, -10...+220 °C/1 K	1
666 6522	Heating Mantle, 250 ml	1
300 76	Laboratory stand II	2
666 4660	Adhesive magnetic board, 300 mm	6
666 4662	Spring clips, magnetic, size 3, 11...14 mm	2
666 4663	Spring clips, magnetic, size 5, 18...22 mm	2
666 4661	Spring clips, magnetic, size 2, 9...11 mm	1
666 4665	Spring clips, magnetic, size 7a, 30...32 mm	1
666 428	Panel frame C100, two-level, for CPS	1
664 153	Watch glass dish, 60 mm diam.	2
661 083ET20	Wooden turnings, 200 pcs	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 052	Test tube rack, for 12 tubes, 18 mm diam., 6 drying pegs	1*
604 170	Powder funnel d=65mm	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
661 082	Stopcock grease, 60 g	1
674 0800	Paraffine, thick, 100 ml	1
674 1980	Bead catalyst, 100 g	1
671 8400	Iron wool, 50 g	1
672 1210	Glycerine, 99 %, 250 ml	1

* additionally recommended

Distillation can only extract materials which are naturally present in the crude oil to start with. Because the share of petrol in the crude oil is insufficient to cover the need, however, conversion processes (modification processes) have been developed. They include, along with thermal cracking, also the catalytic cracking which is carried out in experiment C2.3.2.3. Here, paraffin oil is cracked in the heat of a bead catalyst and the gaseous and liquid fractions are collected.



Boiling range distribution of petrol (C2.3.3.1)



C2.3.3

PROPERTIES OF PETROCHEMICAL PRODUCTS

C2.3.3.1
Boiling range distribution of petrol

C2.3.3.2
Boiling range distribution and fractionated distillation of petroleum

Cat.-Nr.	Name	C2.3.3.1	C2.3.3.2
524 018	Pocket-CASSY 2 Bluetooth	1	1
524 220	CASSY Lab 2	1	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*	1*
524 0031	Bluetooth dongle	1*	1*
524 0673	NiCr-Ni adapter S, type K	1	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1	1
665 338	Distillation bridge after Claisen	1	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1	1
667 072	Support ring for round flask, 250 ml, cork	1	1
665 391ET10	Joint clip, plastic, ST 19/26, set of 10	1	1
604 501	PVC tube, 7 mm diam., 1 m	2	1
604 460	Hose clamp, 8...12 mm	2	2
665 754	Measuring cylinder, 100 ml, with plastic base	1	
667 305	Screw cap, GL 18, with hole	1	1
667 295	Silicone gaskets, GL 18/8, set of 10	1	1
666 194	Protective sleeves for temperature sensors, set of 5	1	1
666 6523	Heating Mantle, 250 ml, adjustable	1	1
300 76	Laboratory stand II	1	1
666 4659	Adhesive magnetic board, 500 mm	2	2
666 4662	Spring clips, magnetic, size 3, 11...14 mm	2	2
666 4663	Spring clips, magnetic, size 5, 18...22 mm	2	2
666 425	Panel frame C50, two-level, for CPS	1	1
661 091	Boiling stones	1	1
670 8200	Petroleum ether, 90...110 °C, 250 ml	1	
661 082	Stopcock grease, 60 g	1	1
664 300	Round-bottom flask, 100 ml, ST 19/26		3
667 071	Support ring for round flask, 100 ml, cork		3
667 227	Glass stopper for ST 19/26		3
661 0771	Warning labels, GHS		1
661 081	Aluminium, foil, 1 roll		1
674 5840	Crude oil, artificial, 1 L		1
674 5810	Crude oil, 500 ml		1*
	additionally required: PC with Windows XP/Vista/7/8	1	1

* additionally recommended

Petrochemistry concerns the production and further processing of organic raw materials based on oil and natural gas. Petrochemical products are always mixtures of many hydrocarbons - only very rarely are pure substances involved! The various hydrocarbon groups are differentiated from one another based on their boiling points. Petrol, for example, is the hydrocarbon mixture which boils between 40 °C and 220 °C.

The petrol fraction, in turn, is subdivided into several subgroups, so-called special petrols. Petrol benzene boils between 40 °C and 70 °C, for example, and regular petrol boils between 65 °C and 90 °C. In experiment C2.3.3.1, a boiling point analysis is carried out on petrol. For this purpose, different petrol fractions are heated in a distillation apparatus in order to determine the boiling range.

In a fractionated distillation of crude oil, fractions of different boiling ranges can be separated. In experiment C2.3.3.2, a fractionated distillation of crude oil is carried out and the fractions are characterised according to their boiling points.



Synthesis and use of indigo (C2.4.1.1)

C2.4.1
SYNTHESIS OF ORGANIC COMPOUNDS

C2.4.1.1
Synthesis and use of indigo

Cat.-Nr.	Name	C2.4.1.1
664 246	Erlenmeyer flask, DURAN, 100 ml, wide neck	1
665 161	Büchner funnel, 45 mm diam.	1
661 030	Round filter, type 595, 40 mm diam., 100 pcs.	1
665 060	Rubber collars, set of 7	1
664 865	Suction flask, 250 ml, glass	1
382 21	Stirring thermometer, -30...+110 °C	1
666 967	Spoon-ended spatula, stainless steel, 150 mm	1
665 751	Measuring cylinder, 10 ml, with plastic base	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
665 996	Graduated pipette, 5 ml	3
666 003	Pipetting ball	1
665 953	Droppers, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs.	1
664 103	Beaker, DURAN, 250 ml, squat	1
664 101	Beaker, DURAN, 100 ml, squat	2
664 154	Watch glass dish, 80 mm diam.	1
667 7977	Electronic Balance 200 : 0,01	1
375 56	Water jet pump	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
666 839	Magnetic stirrer with hot plate	1
673 9390	2-Nitrobenzaldehyde, 5 g	1
670 0410	Acetone, 1 l	1
673 8420	Soda lye, 1 mol/l, 500 ml	1
671 9711	Ethanol, absolute, 500 ml	1
671 6700	Diethylether, 250 ml	1
673 6310	Sodium dithionite, 250 g	1
673 6810	Sodium hydroxide, pellets, 250 g	1
	additionally required: white cotton cloth	1

The synthesis of new compounds is a major branch of organic chemistry. Because carbon and the heteroatoms oxygen, nitrogen and sulphur can be linked together in so many different combinations, the number of compounds characterised increases year after year. Every synthesis of a new compound consists of carrying out a chemical reaction and subsequently purifying the reaction mixture.

Indigo, a dye, can be produced in a simple organic synthesis. In so doing, o-nitrobenzaldehyde reacts with acetone in a condensation reaction to form isatin. That dimerises into finished indigo. Indigo is not water soluble and can simply be filtered out after the reaction. In experiment C2.4.1.1, this reaction is carried out and the finished indigo is used as a dye.



Soxhlet extraction from leaves (C2.4.2.1)

C2.4.2
EXTRACTION AS A PURIFICATION PROCESS

C2.4.2.1
Soxhlet extraction from leaves

Cat.-Nr.	Name	C2.4.2.1
665 453	Extraction unit after Soxhlet	1
665 422	Counter-flow coller after Dimroth	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
665 391ET10	Joint clip, plastic, ST 19/26, set of 10	1
665 392ET10	Joint clip, plastic, ST 29/32, set of 10	1
666 6523	Heating Mantle, 250 ml, adjustable	1
300 76	Laboratory stand II	1
300 01	Stand base, V-shaped, large	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
666 555	Universal clamp, 0...80 mm	2
301 09	Bosshead S	2
667 193	PVC tubing, 7 mm diam., 1 m	2
604 460	Hose clamp, 8...12 mm	2
661 050	Extraction thimbles, 80 x 26 mm diam., 25 pieces	1
667 027	Tweezers, blunt, 130 mm	1
602 954	Measuring cylinder, Boro 3.3, 250 ml, glass base	1
667 7977	Electronic Balance 200 : 0,01	1
661 167	Narrow-neck bottle, amber glass, 250 ml	1
665 005	Funnel, Boro 3.3, 100 mm diam.	1
671 9720	Ethanol, denaturated, 1 l	1
661 082	Stopcock grease, 60 g	1
661 091	Boiling stones	1
	additionally required: leaves, dry, fine powder	1

The term 'extraction' refers to the process of dissolving out individual substances from the extraction material, a liquid or solid mixture of substances. For this it takes a suitable solvent - the extraction agent - in which ideally only the substance to be dissolved out (the extract) dissolves.

When low solubility or insoluble solids are to be extracted, then a Soxhlet extraction is carried out as in experiment C2.4.2.1. In this case the vapourised solvent condenses on a chiller and drips onto the extraction material in a filter sleeve. It collects in the extraction space, draws the extract out of the extraction material, and is automatically drawn into the flask. From there the solvent evaporates once again (without extract).



Extracting pigments from leaf extract (C2.4.2.2)

C2.4.2
EXTRACTION AS A PURIFICATION PROCESS

C2.4.2.2
Extracting pigments from leaf extract

Cat.-Nr.	Name	C2.4.2.2
665 123	Separating funnel, 250 ml, ungraduated	1
300 01	Stand base, V-shaped, large	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 573	Stand ring with stem, 100 mm diam.	1
667 180	Rubber tubing, 1 m x 7 mm diam., DIN 12865	1
667 016	Scissors, 200 mm, pointed	1
664 103	Beaker, DURAN, 250 ml, squat	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
610 061	Safety gloves	1
	additionally required: Cooking oil, leaf extract from experiment C2.4.2.1	1

The solvent extraction of a substance is a simple liquid-liquid extraction. In this case the extraction material is shaken with the extraction agent in a closed vessel, the separatory funnel. The liquids must not be miscible! The substance to be extracted goes over to the extraction agent. In experiment C2.4.2.2 this technique is illustrated by the solvent extraction of a leaf extract with oil.





C2.4.3
DISTILLATION AS A PURIFICATION PROCESS

C2.4.3.1
Distillation of red wine

Distillation of red wine (C2.4.3.1)

Cat.-Nr.	Name	C2.4.3.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
665 338	Distillation bridge after Claisen	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
664 300	Round-bottom flask, 100 ml, ST 19/26	1
665 391ET10	Joint clip, plastic, ST 19/26, set of 10	1
604 501	PVC tube, 7 mm diam., 1 m	2
604 460	Hose clamp, 8...12 mm	2
667 305	Screw cap, GL 18, with hole	1
667 295	Silicone gaskets, GL 18/8, set of 10	1
666 194	Protective sleeves for temperature sensors, set of 5	1
666 6522	Heating Mantle, 250 ml	1
300 76	Laboratory stand II	1
666 4659	Adhesive magnetic board, 500 mm	1
666 4662	Spring clips, magnetic, size 3, 11...14 mm	2
666 4663	Spring clips, magnetic, size 5, 18...22 mm	2
666 425	Panel frame C50, two-level, for CPS	1
661 091	Boiling stones	1
661 082	Stopcock grease, 60 g	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

Distillation is a purification process for separating fluids from one another. It relies on the different volatilities and boiling points of the components.

In distillation, the liquid mixture is heated and the vapours are re-cooled. The composition of the vapours differs from that of the liquid, and the same also applies then to the condensate.

If the boiling points are far enough apart, then mixtures can be separated by simple distillation. This is the case, for example, in the distillation of red wine in experiment C2.4.3.1. Ethanol boils at 78 °C and water boils at 100 °C. Here CASSY is used to track the temperature curve in computerised form.



Purification of a substance with water vapour distillation (C2.4.3.3)

C2.4.3
DISTILLATION AS A PURIFICATION PROCESS

C2.4.3.3
Purification of a substance with water vapour distillation

Cat.-Nr.	Name	C2.4.3.3
666 4659	Adhesive magnetic board, 500 mm	2
666 4662	Spring clips, magnetic, size 3, 11...14 mm	1
666 4663	Spring clips, magnetic, size 5, 18...22 mm	2
666 6522	Heating Mantle, 250 ml	1
665 338	Distillation bridge after Claisen	1
664 300	Round-bottom flask, 100 ml, ST 19/26	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
665 391ET10	Joint clip, plastic, ST 19/26, set of 10	1
666 425	Panel frame C50, two-level, for CPS	1
666 161	Chemical thermometer, -10...+220 °C/1 K	1
300 76	Laboratory stand II	1
604 501	PVC tube, 7 mm diam., 1 m	2
604 460	Hose clamp, 8...12 mm	2
667 305	Screw cap, GL 18, with hole	1
667 295	Silicone gaskets, GL 18/8, set of 10	1
661 091	Boiling stones	1
661 082	Stopcock grease, 60 g	1
	additionally required: one lemon or orange	1

In experiment C2.4.3.3, water vapour distillation is used to isolate fragrance and flavouring substances from crushed plant parts. The readily volatile fragrance and flavouring substances are carried away by the hot steam. In addition, the water solubility of these essential oils is temperature dependent. They dissolve in the hot water in the receiver flask. During cooling in the distillation unit, the water and essential oil separate again. In this way, the oil can be easily separated from the solvent water.



Separation of a leaf extract with column chromatography (C2.4.4.1)

C2.4.4
COLUMN CHROMATOGRAPHY AS A PURIFICATION PROCESS

C2.4.4.1
Separation of a leaf extract with column chromatography

C2.4.4.2
Separation of petroleum by means of column chromatography

Cat.-Nr.	Name	C2.4.4.1	C2.4.4.2
665 592	Chromatography column, 235 x 20 mm diam.	1	1
665 073	Dropper funnel, 75 ml, ST 29, graduated	1	
664 101	Beaker, DURAN, 100 ml, squat	2	2
602 013	Beaker, Boro 3.3, 800 ml, tall	1	1
667 092	Mortar, porcelain, 70 mm Ø	1	
667 091	Pestle, 100 mm long	1	
665 005	Funnel, Boro 3.3, 100 mm diam.	1	
661 038	Round filter, Type 595, 150 mm diam., 100 pcs.	1	
661 161	Narrow-neck glass bottle, amber glass, 100 ml	1	
602 347	Laboratory bottle, 500 ml, GL 45 thread	1	1
665 754	Measuring cylinder, 100 ml, with plastic base	1	
665 756	Measuring cylinder, 500 ml, with plastic base	1	2
665 217	Glass stirring rod, 500 mm x 8 mm diam., set of 10	1	1
665 025	Powder funnel, 100 mm diam., plastic	1	1
604 5682	Powder spatula, steel, 185 mm	1	1
661 0771	Warning labels, GHS	1	1
667 050	Test tube rack, plastic, for 9 tubes, 18 mm diam.	1	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1	1
667 253	Rubber stopper, solid, 14...18 mm diam.	9	9
666 966	Spoon-ended spatula, PP, 180 mm	1	
665 953	Droppers, 7 x 150 mm, 10 pcs.	1	
666 584	Filtration stand for two funnels	1	
665 954	Rubber bulbs, 10 pcs.	1	
300 02	Stand base, V-shaped, small	1	1
300 42	Stand rod, 47 cm, 12 mm diam.	1	1
301 09	Bosshead S	2	2
666 555	Universal clamp, 0...80 mm	2	2
670 8200	Petroleum ether, 90...110 °C, 250 ml	1	

Cat.-Nr.	Name	C2.4.4.1	C2.4.4.2
672 1000	Glass wool, 10 g	1	1
674 8210	Sea sand, purified, 1 kg	1	1
670 0410	Acetone, 1 l	1	1
661 058	Silica gel, 35-70 mesh, 500 g	1	
661 082	Stopcock grease, 60 g	1	1
602 385	Dropper funnel, 50 ml, spherical		1
674 5840	Crude oil, artificial, 1 L		1
674 5810	Crude oil, 500 ml		1*
670 2910	Aluminium oxide, 500 g		1
674 2220	Petroleum ether, 40...70 °C, 1 l		1
	additionally required: green leaves, dry or fresh	1	

* additionally recommended

After a synthesis, the resulting reaction mixture is often separated by means of column chromatography. Often used is a solid-liquid adsorption chromatography, which takes advantage of the different polarities of the individual compounds.

The process of chromatography was developed by Tsvet on leaf pigments at the beginning of the 20th century. Although ridiculed at first, the technique has since become one the most important methods in organic chemistry. In experiment C2.4.4.1, a leaf extract is produced and separated into its components by means of column chromatography.

Crude oil is a liquid mixture of many organic substances. The aromatic substances in the crude oil can be separated on aluminium oxide by means of column chromatography. This is carried out in experiment C2.4.4.2. Using column chromatography, however, it is also possible to assay the different compound classes in crude oil fractions.

C3 ANALYTIC CHEMISTRY



Determination of the density of gases (C3.1.1.1)

C3.1.1
PROPERTIES OF GASES

C3.1.1.1
Determination of the density of gases

Cat.-Nr.	Name	C3.1.1.1
379 07	Sphere with 2 stop-cocks, glass, 1 l	1
667 072	Support ring for round flask, 250 ml, cork	1
OHS PU123	Electronic precision balance SPU123	1
375 58	Hand vacuum pump	1
665 913	Gas syringe, 100 ml with 1-way stopcock	1
661 000	Minican pressurised gas canister, nitrogen	1
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
667 183	Rubber tubing, 1 m x 8 mm diam., DIN 12865	1
604 510	Hose connector, 4...15 mm	1
661 082	Stopcock grease, 60 g	1

A gas is a collection of molecules which are separated by great distances from one another and are in chaotic motion. It completely fills any volume which is available to it. In so doing, it always has the same volume, regardless of which gas it is. Because of the large molecular distances, gases are highly compressible.

Density (σ) is defined as mass (*m*) per unit volume (*V*):

$$\sigma = \frac{V}{m}$$

In experiment C3.1.1.1, a sphere of known volume with two stopcocks is used to determine the density of various gases. The mass of the enclosed air is determined from the measured difference between the total weight of the sphere filled with gas and the empty weight of the evacuated sphere.



Determination of viscosity with the falling ball viscometer according to Höppler (C3.1.2.1)

C3.1.2
PROPERTIES OF LIQUIDS

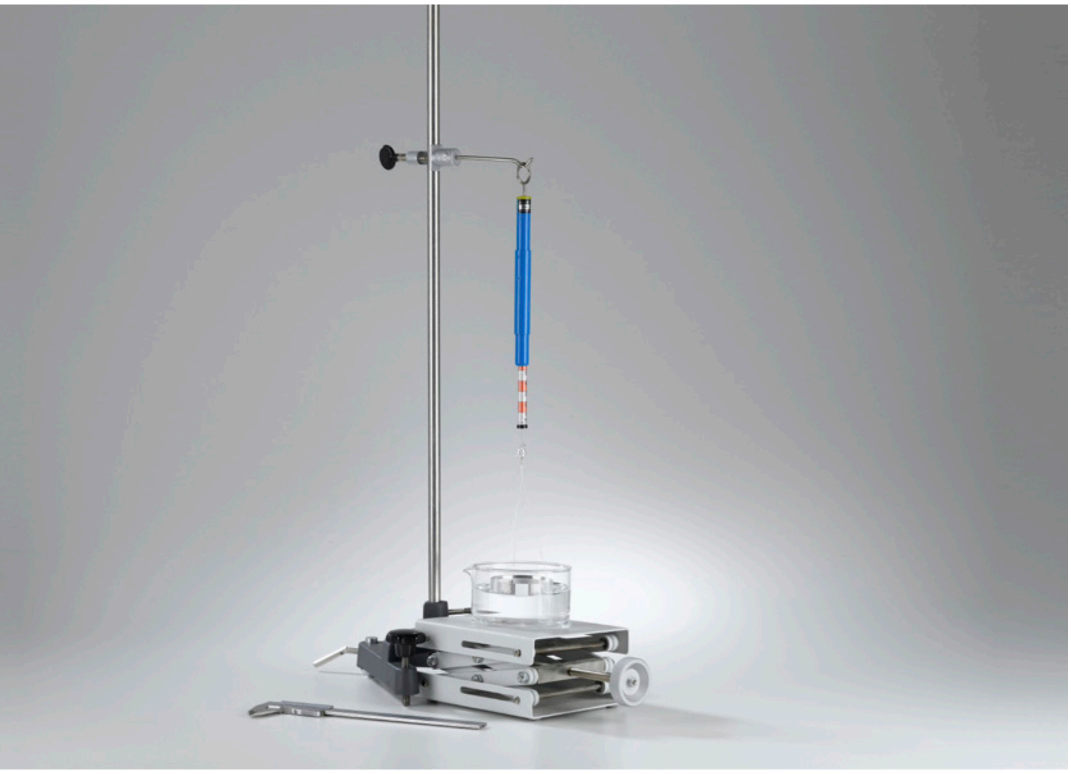
C3.1.2.1
Determination of viscosity with the falling ball viscometer according to Höppler

Cat.-Nr.	Name	C3.1.2.1
665 906	Höppler falling ball viscometer	1
313 07	Hand-held stop-watch I, mechanical	1
666 7681	Circulation thermostat SC 100-S5P	1
667 194	Silicone tubing, 7 mm diam., 1 m	2
OHC S-200E	Electronic balance, CS200E	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
664 138	Beaker, Boro3.3, 250 ml, tall	1
666 963	Spoon-ended spatula, stainless steel, 120 mm	1
674 6050	D(+)-Saccharose, 100 g	1
675 3410	Water, pure, 5 l	2

Liquid particles glide easily alongside one another. A liquid conforms to the shape of the vessel in which it is placed. All objects which are heavier than the liquid sink into it unimpeded. The surface of liquids always remains horizontal. Liquids cannot be compressed.

When a substance (gas, liquid or solid) deforms, it opposes the change in form by a resistance which is generally referred to as its viscosity. If one liquid layer moves at constant speed in a direction parallel to a second layer, then a force friction acts between the two layers. The friction converts the energy of motion into heat. For this reason, the viscosity of a substance is a measure of the internal friction. The viscosity of a substance determines how well or poorly it flows in a pipe (e.g. blood through a vein) and how much resistance it exerts against a solid body moving in it.

Viscosity is highly temperature dependant. Experiment C3.1.2.1 studies the dependence of the viscosity on concentration in concentrated sugar solutions at room temperature.



Measurement of surface tension using the „break-away“ method (C3.1.2.2)

C3.1.2
PROPERTIES OF LIQUIDS

C3.1.2.2
Measurement of surface tension using the „break-away“ method

Cat.-Nr.	Name	C3.1.2.2
367 46	Surface tension determination device	1
664 175	Crystallisation dish, 95 mm diam., 300 ml	1
314 111	Precision dynamometer , 0.1 N	1
311 53	Vernier callipers	1
300 76	Laboratory stand II	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 08	Clamp with hook	1
671 9740	Ethanol, denaturated, 250 ml	1
675 3400	Water, pure, 1 l	1

Surface tension is a property of the surface (boundary layer) between a fluid and a gas, such as air. The surface of a liquid behaves like a stretched elastic film. This effect is the reason that water droplets form, for example, and helps make it possible for certain insects to walk on the water or for a coin to "swim" on the water. Experiment C3.1.2.2 determines the surface tension of water and ethanol. Here it will be shown that water is characterised by a particularly high surface tension as compared with other liquids. (Published value for water: 0.073 Nm^{-1}, for ethanol: 0.022 Nm^{-1}).



Determination of density with the pycnometer (C3.1.2.4)

C3.1.2
PROPERTIES OF LIQUIDS

C3.1.2.3
Determination of density according to Mohr-Westphal

C3.1.2.4
Determination of density with the pycnometer

Cat.-Nr.	Name	C3.1.2.3	C3.1.2.4
362 025	Plumb bob	1	
315 011	Hydrostatic balance	1	
315 31	Set of weights, 10 mg to 200 g	1	
382 21	Stirring thermometer, -30...+110 °C	1	1
665 754	Measuring cylinder, 100 ml, with plastic base	2	2
664 138	Beaker, Boro3.3, 250 ml, tall	1	
671 9720	Ethanol, denaturated, 1 l	1	1
666 145	Gay-Lussac pycnometer, 50 ml		1
667 7977	Electronic Balance 200 : 0,01		1

Experiment C3.1.2.3 provides a plummet for determining the of density of liquids. The measurement task is to determine the density of ethanol-water mixtures. Using the plummet, the density is determined from the buoyancy that a body of known volume experiences in the liquid under examination.

Experiment C3.1.2.4 provides a pycnometer according to Gay-Lussac for determining the of density of liquids. The measurement task is to determine the density of ethanol-water mixtures. The pycnometer is a bulb-shaped bottle into which the liquid under study is filled for weighing. The volume capacity of the pycnometer is determined by weighing with a liquid of known density (e.g. water).



Determination of the melting point of salicylic acid (C3.1.3.1)

C3.1.3
PROPERTIES OF SOLIDS

C3.1.3.1
Determination of the melting point of salicylic acid

Cat.-Nr.	Name	C3.1.3.1
667 500	Melting point determination apparatus	1
661 085	Melting point detection tubes, set of 100	1
667 307	Silicone gaskets, GL 18, solid, set of 10	1
666 161	Chemical thermometer, -10...+220 °C/1 K	1
666 8471	Magnetic stirrer with hotplate	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp, 0...80 mm	1
301 09	Bosshead S	1
602 725	Laboratory dish, 140 mm diam., 900 ml	1
674 0820	Paraffin, thick, 1 l	1
674 6210	Salicylic acid, 100 g	1

The solid state of a substance is defined as featuring a definite, nearly temperature-independent volume and stable shape. All substances which meet those criteria are known as solids.

In experiment C3.1.3.1, the thiele tube is used to determine the melting point of salicylic acid. The melting point is, along with the boiling point, a characteristic property of every substance. The melting point determination apparatus is filled with paraffin and fitted with a thermometer. A melting point tube is filled with the substance to be assayed. The tube is inserted with the open side into the device in a way that it is positioned alongside the thermometer. The melting point is determined by slow heating in the water bath.



Determination of the density of solids (C3.1.3.4)

C3.1.3

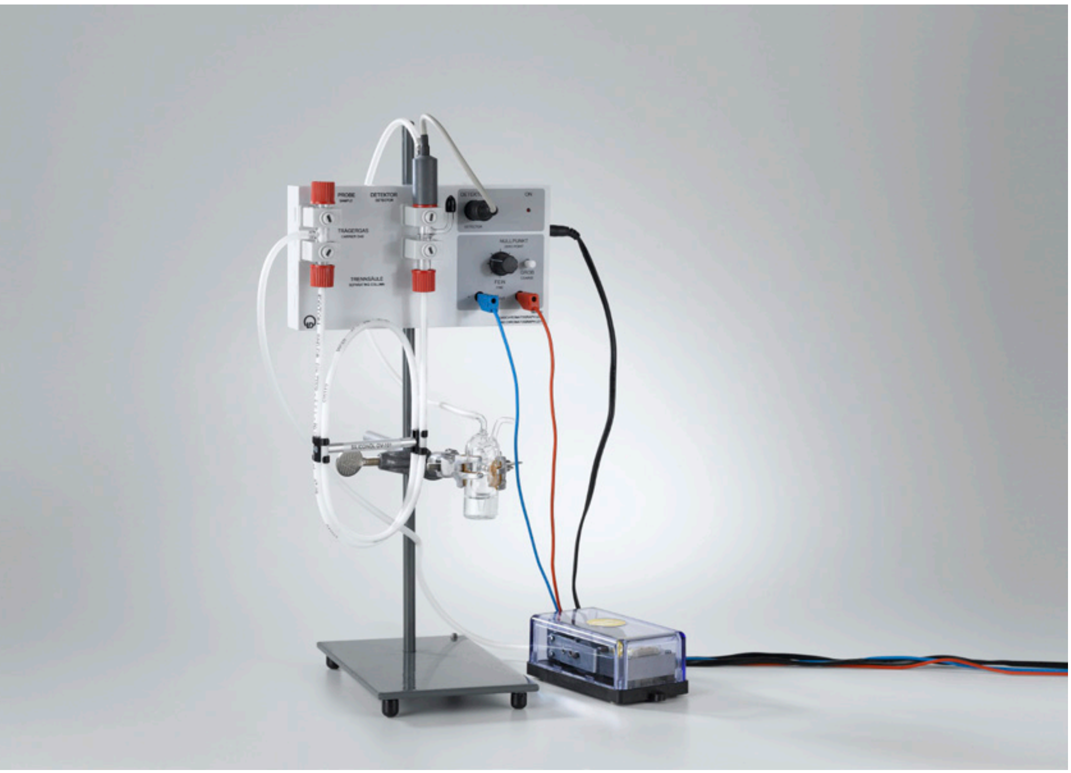
PROPERTIES OF SOLIDS

C3.1.3.4
Determination of the density of solids

Cat.-Nr.	Name	C3.1.3.4
667 7977	Electronic Balance 200 : 0,01	1
362 04	Overflow vessel	1
590 08ET2	Measuring cylinders, 100 ml, set of 2	1
300 76	Laboratory stand II	1
309 48ET2	Fishing line, set of 2	1
674 7560	Sulfur, Pcs., 500 g	1
309 42	Colouring, red, 10 g	1*

* additionally recommended

Experiment C3.1.3.4 determines the density of irregularly shaped solid bodies. Weighing is coupled with a measurement of volume. The volume of the bodies are determined by the volume of liquid which the bodies displace from an overflow vessel.





C3.2.1
GAS CHROMATOGRAPHY

C3.2.1.1
Gas chromatographical analysis of cigarette lighter gas (butane gas)

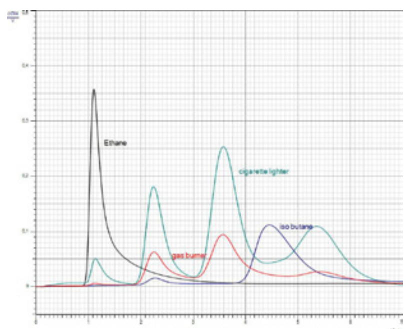
Gas chromatographical analysis of cigarette lighter gas (butane gas) (C3.2.1.1)

Cat.-Nr.	Name	C3.2.1.1
665 580	Gas chromatograph LD 1	1
665 582	Hydrocarbon sensor	1
665 5831	Separation column silicone OV101	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 0621	UIP sensor S	1
662 2861	Aquarium pump, 100 l/h	1
664 814	Bubble counter, with flash back valve	1
665 957	Disposable syringe, 1 ml, with Luer fitting	1
665 960	Cannula, 0.45 diam., 10 pcs., with Luer fitting	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
666 503	Base plate for bunsen stand, 130 x 210 mm	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp, 0...80 mm	1
301 09	Bosshead S	1
665 589	Septa, silicone, 13 mm diam., 10 pcs.	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
660 980	Fine regulating valve for minican gas canisters	1
660 988	Minican pressurised gas canister, ethane	1
660 989	Minican pressurised gas canister, n-Butane	1
	additionally required: cigarette lighter(s)	1

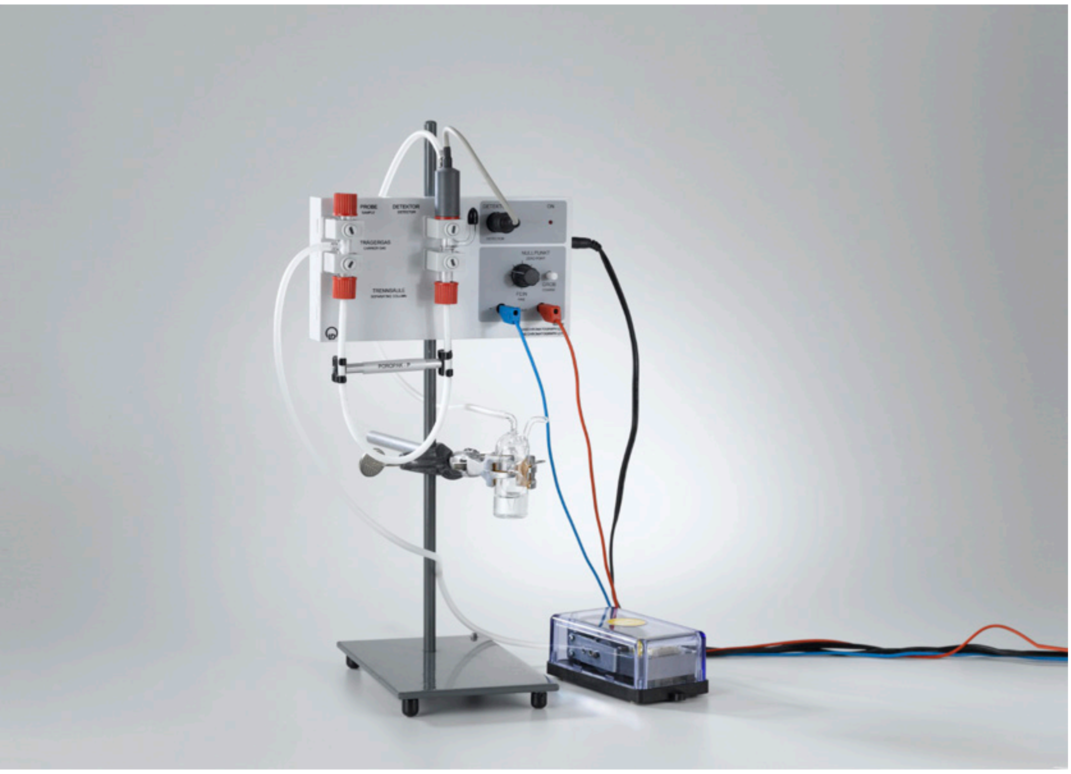
* additionally recommended

In use all around the world today, gas chromatography is a method for analyzing chemical substances and mixtures. Especially useful for identifying the components of gaseous hydrocarbons, e.g. natural gas, it can also be used to study volatile substances such as fragrances or alcohols. Substances are separated in a two-phase system comprising a stationary phase – the separation column with column material – and a mobile phase – the carrier gas. Samples are introduced into the carrier gas stream and travel along the column at different speeds depending on polarity, which makes it possible to separate them.

Cigarette lighter gas is a mixture of different gaseous hydrocarbons. They can be easily separated by gas chromatography techniques. The stationary phase is silicone oil OV-101 on silica gel. Air is used as the mobile phase. The proportions of the individual hydrocarbons in the gas mixture is different in every cigarette lighter – depending on the source of the natural gas. This is studied in experiment C3.2.1.1.



Chromatogram of the analysis of lighter gases





C3.2.1
GAS CHROMATOGRAPHY

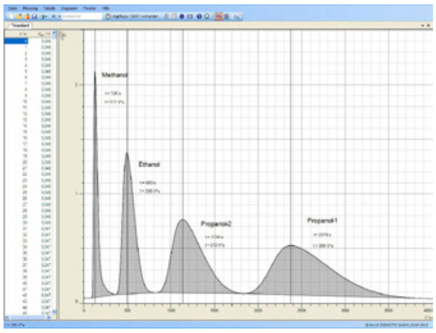
C3.2.1.2
Gas chromatographical separation of alcohols

Gas chromatographical separation of alcohols (C3.2.1.2)

Cat.-Nr.	Name	C3.2.1.2
665 580	Gas chromatograph LD 1	1
665 582	Hydrocarbon sensor	1
665 584	Separation column with Porapak P	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 0621	UIP sensor S	1
662 2861	Aquarium pump, 100 l/h	1
664 814	Bubble counter, with flash back valve	1
665 617	Microlitre syringe, 1 µl	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
666 503	Base plate for bunsen stand, 130 x 210 mm	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp, 0...80 mm	1
301 09	Bosshead S	1
665 589	Septa, silicone, 13 mm diam., 10 pcs.	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
673 2700	Methanol, 250 ml	1
671 9700	Ethanol, absolute, 250 ml	1
674 4310	1-Propanol, 250 ml	1
674 4400	2-Propanol, 250 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

A gas chromatograph can be used to separate not only gaseous substances, but also volatile liquids. Only the gaseous part is separated, however. In such cases, the separation column and the carrier gas can be warmed if necessary. In experiment C3.2.1.2, the gas chromatographic analysis of an alcohol mixture is carried out.



Chromatogram of the analysis of different alcohols



Absorption spectra of pigments on a screen (C3.3.1.1)

C3.3.1
SPECTROMETRY

C3.3.1.1
Absorption spectra of pigments on a screen

C3.3.1.2
Recording of absorption spectra with a spectrometer

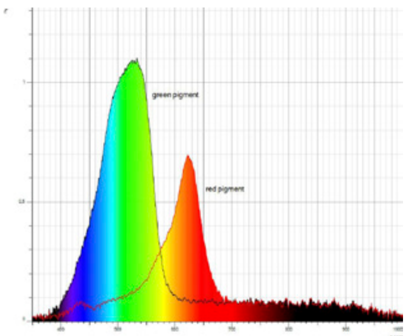
Cat.-Nr.	Name	C3.3.1.1	C3.3.1.2
460 03	Lens in frame, f=100 mm	1	1
466 05	Direct vision prism	1	
466 04	Holder for direct vision prism	1	
477 14	Plate glass cell (cuvette), 50 x 50 x 20 mm	1	1
460 25	Prism table	1	1
441 53	Screen, translucent	1	
450 60	Lamp housing with cable	1	1
450 521	Bulbs, 12 V/30 W, E14, set of 2	1	1
460 20	Condenser with diaphragm holder	1	1
521 210	Transformer, 6/12 V	1	1
460 310	Optical bench, S1 profile, 1 m	1	1
460 311	Clamp rider with clamp	5	4
667 7977	Electronic Balance 200 : 0,01	1	1
602 023	Beaker, Boro 3.3, 150 ml, squat	1	
665 754	Measuring cylinder, 100 ml, with plastic base	1	1
672 7010	Potassium permanganate, 250 g	1	
467 251	Compact spectrometer, physics (spectral photometer)		1
460 251	Fibre holder		1
665 996	Graduated pipette, 5 ml		1
666 003	Pipetting ball		1
604 5672	Double microspatula, steel, 150 mm		1
664 103	Beaker, DURAN, 250 ml, squat		1
309 42	Colouring, red, 10 g		1
671 0800	Bromothymol blue solution, 0.1 %, 50 ml		1
672 0110	Fluoresceine, 25 g		1*
	additionally required: PC with Windows XP/Vista/7/8		1

* additionally recommended

The impression of colour observed when looking through liquids is created by the part of the white light which is transmitted („passed through"). Every coloured substance absorbs at characteristic wavelengths. In this way, a characteristic spectrum can be created for a dye.

In experiment C3.3.1.1, the light from a lamp is separated out into its spectrum with a direct vision prism. That light is then projected through coloured liquids and compared with the continuous spectrum of the light from the lamp. The original continuous spectrum with the different spectral colours disappears. Only the colour components of the liquid remain visible.

In experiment C3.3.1.2, the solution of a dye is exposed to the light from a lamp. For the absorption spectrum, the light passing through the coloured solution is recorded with a spectrometer. The absorption spectrum is compared with the continuous spectrum of the light from the lamp.



Spectra of a red and a green pigment



Recording of a fluorescence spectrum with a spectrometer (C3.3.1.3)

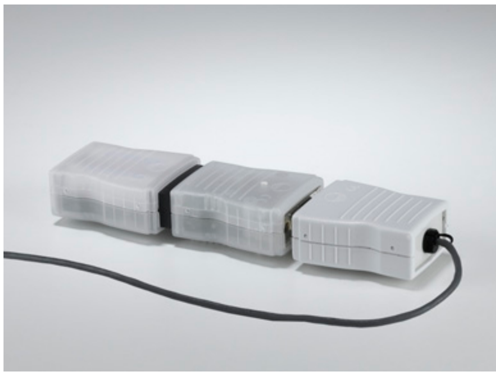
C3.3.1
SPECTROMETRY

C3.3.1.3
Recording of a fluorescence spectrum with a spectrometer

Cat.-Nr.	Name	C3.3.1.3
477 14	Plate glass cell (cuvette), 50 x 50 x 20 mm	1
460 25	Prism table	1
460 03	Lens in frame, f=100 mm	1
450 60	Lamp housing with cable	1
450 521	Bulbs, 12 V/30 W, E14, set of 2	1
460 20	Condenser with diaphragm holder	1
521 210	Transformer, 6/12 V	1
467 251	Compact spectrometer, physics (spectral photometer)	1
460 251	Fibre holder	1
300 02	Stand base, V-shaped, small	1
460 310	Optical bench, S1 profile, 1 m	1
460 311	Clamp rider with clamp	3
604 5672	Double microspatula, steel, 150 mm	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
672 0110	Fluoresceine, 25 g	1
	additionally required: PC with Windows XP/Vista/7/8	1

In experiment C3.3.1.3, a solution of the fluorescent dye fluorescein is exposed to the light from a lamp. For this purpose, the spectrometer is arranged at a right angle to the lamp. In this way, the fluorescence spectrum of the dye can be recorded. This can be compared with the absorption spectrum from experiment C3.3.1.2.





C3.3.2
PHOTOMETRY

C3.3.2.1
The Beer-Lambert law

The Beer-Lambert law (C3.3.2.1)

Cat.-Nr.	Name	C3.3.2.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 069	Immersion photometer S	1
666 2605	Holder for immersion photometer S	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1
665 792	Volumetric flask, Boro 3.3, 50 ml	1
664 045	Test tubes, Fiolax, 30 x 200 mm, set of 10	1
665 995	Graduated pipette, 2 ml	1
665 996	Graduated pipette, 5 ml	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	3
667 054	Test tube rack, for 12 tubes, 32 mm diam.	1
667 7977	Electronic Balance 200 : 0,01	1
672 9700	Copper(II)-sulfate, anhydrous, 50 g	1
670 3600	Ammonia solution, 25 %, 250 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The intensity of light diminishes when it passes through a coloured solution. Photometric measurements make use of this fact to determine the concentration of such a solution. For this purpose, the transmittance T of the solution is measured, i.e. the ratio of the intensity of the transmitted light I to the intensity of light exposure I_0.

$$T = \frac{I}{I_0}$$

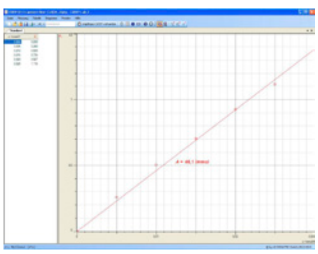
The extinction or absorption of the solution, i.e. the number of light quanta absorbed, is proportional to the concentration. Transmission and extinction have the following relationship:

$$E = \log_{10}\left(\frac{I_0}{I}\right) = -\log_{10}\left(\frac{I}{I_0}\right) = -\log_{10}(T)$$

If the extinction of a solution is measured, its concentration can be calculated from the result. That relationship is expressed by the Beer-Lambert law. Along with the concentration c of a solution, the extinction also depends on the thickness d of the layer and on the substance-specific extinction coefficient ε.

$$E = \log_{10}\left(\frac{I_0}{I}\right) = \varepsilon \cdot c \cdot d$$

In experiment C3.3.2.1, a dilution series is used to study the proportional relationship between extinction and concentration and to determine the extinction coefficient of blue copper tetraammine.



Dilution series of copper tetraammine



C3.3.3
REFRACTOMETRY

C3.3.3.1
Determination of the refractive index with the refractometer

Determination of the refractive index with the refractometer (C3.3.3.1)

Cat.-Nr.	Name	C3.3.3.1
667 359	Laboratory refractometer	1
667 7977	Electronic Balance 200 : 0,01	1
602 020	Beaker, Boro 3.3, 25 ml, squat	5
665 953	Droppers, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs.	1
661 243	Wash bottle, PE, 500 ml	1
604 5661	Spatula, double ended, 185 mm	1
673 5700	Sodium chloride, 250 g	1
671 9720	Ethanol, denaturated, 1 l	1

Every liquid has a characteristic refractive index n_D. The refractive index of a mixture of two liquids is determined by the refractive index of the individual liquids and by their proportion in the mixture. If the refractive indices of the individual liquids are known, then their mixing proportion in a solution can be determined. The refractive index is measured with a refractometer.

The refractometer is also useful for determining the Brix value (mass for the soluble solids or sugar content). In experiment C3.3.3.1, the refractometer is used to determine the mass fraction w in % in a solution by measuring the refractive index. (w = the mass of the components / the mass of the mixture. To express the result in percent, the number is multiplied by 100). For this purpose, solutions with different mass fractions of a substance are prepared. In this way, a sample with unknown mass fraction can be determined.



Rotation of the polarisation plane through sugar solutions (C3.3.4.1)

C3.3.4
POLARIMETRY

C3.3.4.1
Rotation of the polarisation plane through sugar solutions

Cat.-Nr.	Name	C3.3.4.1
657 591	Polarimeter	1
OHC S-200E	Electronic balance, CS200E	1
666 963	Spoon-ended spatula, stainless steel, 120 mm	1
665 793	Volumetric flask, Boro 3.3, 100 ml	3
664 137	Beaker, Boro3.3, 100 ml, tall	3
672 1100	D(+)-Glucose, 100 g	1
672 0700	D(-)-Fructose, 50 g	1
674 6050	D(+)-Saccharose, 100 g	1

The term 'optical activity' refers to the property of some materials which rotate the polarisation plane of linearly polarised light as it passes through a substance. The angle of rotation α depends on the molecular structure and the concentration of the dissolved substance, on the distance that the light travels through the solution, and on the wavelength of the light.

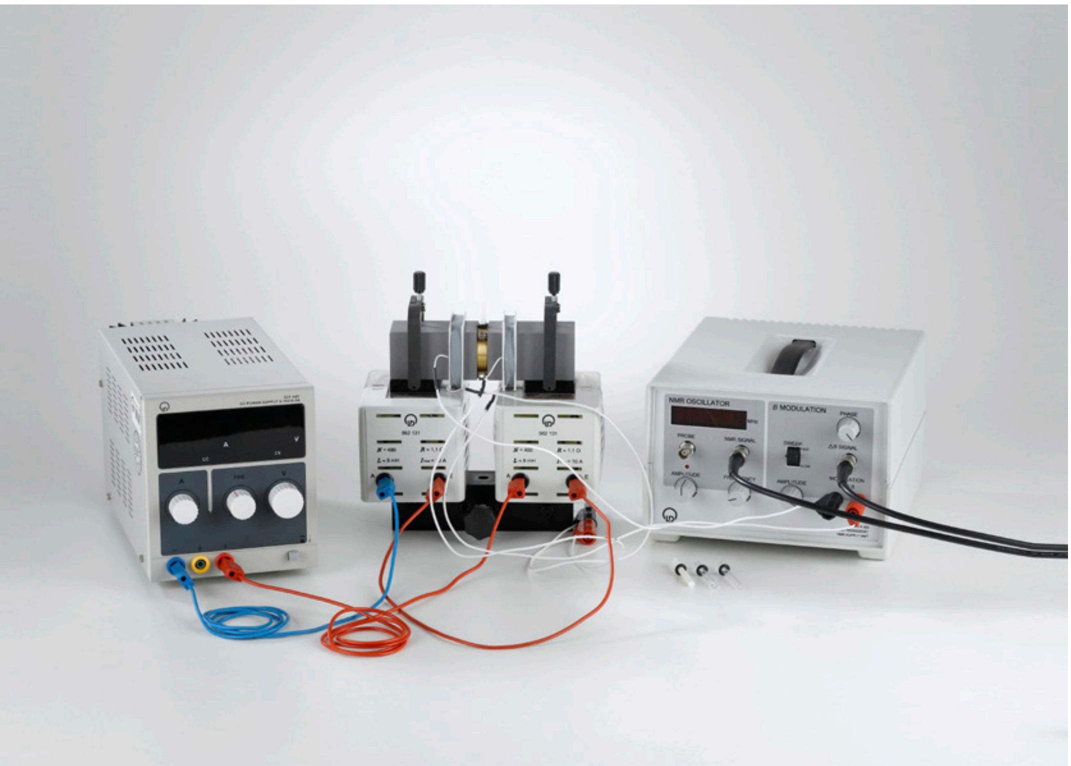
Experiment C3.3.4.1 demonstrates that optically active substances can rotate the plane of a linerally polarised beam of light by a specific value. For a given cuvette length *d*, the angle of rotation α of an optically active solution is proportional to the concentration *c* of the solution.

To determine the concentration *c* of the solution, the following expression applies:

$$c = \frac{\alpha}{l \cdot [\alpha]}$$

specific rotation: $[\alpha]$ (°· ml/g · dm)

The angle of rotation is given as a positive (+) value when the polarisation plane of the light directed toward the observer rotates clockwise (to the right). Counterclockwise rotation is referred to as rotation to the left and expressed as a negative number, hence preceded by a minus sign (-).





C3.4.3 NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY (NMR SPECTROSCOPY)

C3.4.3.1 Nuclear magnetic resonance (NMR) on polystyrene, glycerine and Teflon

Nuclear magnetic resonance (NMR) on polystyrene, glycerine and Teflon (C3.4.3.1_a)

Cat.-Nr.	Name	C3.4.3.1 (a)	C3.4.3.1 (b)
514 602	NMR supply unit	1	1
514 606	NMR probe	1	1
562 11	U-core with yoke	1	1
562 131	Coil, 480 turns, 10 A	2	2
521 546	DC Power Supply 0 ... 16 V, 0 ... 5 A	1	1
575 212	Two-channel oscilloscope 400	1	
501 02	BNC cable, 1 m	2	
531 835	Universal measuring instrument, Physics	1*	1*
524 0381	Combi B sensor S	1*	1*
501 11	Extension cable, 15 pin	1*	1*
500 621	Safety connection lead, 50 cm, red	1	1
500 641	Safety connection lead, 100 cm, red	1	1
500 642	Safety connection lead, 100 cm, blue	1	1
524 013	Sensor-CASSY 2		1
524 220	CASSY Lab 2		1
575 24	Screened cable, BNC/4 mm		2
	additionally required: PC with Windows XP/Vista/7/8		1

* additionally recommended

In a magnetic field B, the magnetic moment of a nucleus associated with nuclear spin I takes on the following energy states:

$$E_m = -g_I \cdot \mu_K \cdot m \cdot B \quad \text{with} \quad m = -I, \; -I+1, \; \ldots, \; I$$

$$\mu_K = 5.051 \cdot 10^{-27} \frac{\text{J}}{\text{T}}: \text{ nuclear magneton}$$

g_I: g factor of nucleus

A high-frequency magnetic field with frequency f projected perpendicular to that magnetic field excites transitions between neighbouring energy states when they meet the resonance conditions:

$$h \cdot \nu = E_{m+1} - E_m$$

h: Planck's constant

This phenomenon is the basis for nuclear magnetic resonance (NMR). Nuclei with an uneven number of protons are active here. The exact resonance frequency of a nucleus depends on the type of the atom and on its chemical surroundings. Along with the outer magnetic field B, a local, inner field also affects every nucleus. This is generated by the nuclei in the immediate proximity. In this way, NMR is useful for analyzing structures.

In experiment C3.4.3.1, nuclear magnetic resonance is demonstrated on polystyrene, glycerine and Teflon. The position, width and intensity of the resonance lines are evaluated. The recording is made with an oscilloscope in variant a and with Sensor-CASSY 2 and CASSY Lab 2 in variant b.

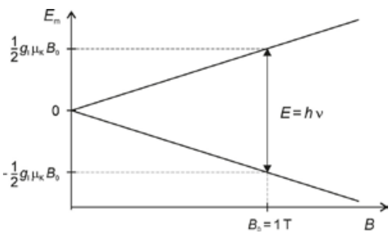


Diagram of resonance condition of hydrogen



Electron spin resonance on DPPH (C3.4.4.1)

C3.4.4
ELECTRON SPIN RESONANCE SPECTROSCOPY

C3.4.4.1
Electron spin resonance on DPPH

Cat.-Nr.	Name	C3.4.4.1
514 55	ESR basic unit	1
514 571	ESR supply unit	1
555 604	Pair of Helmholtz coils	1
575 212	Two-channel oscilloscope 400	1
501 02	BNC cable, 1 m	2
300 11	Saddle base	3
501 23	Connecting lead, 32 A, 25 cm, black	1
501 25	Connecting lead, 32 A, 50 cm, red	1
501 26	Connecting lead, 32 A, 50 cm, blue	1

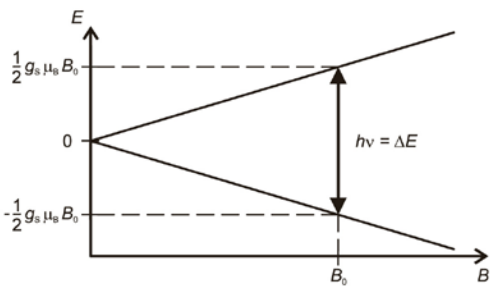


Diagram of resonance condition of free electrons

In the magnetic field, the magnetic moment of the unpaired electron with the total angular momentum j takes on the discrete energy states:

$$E_m = -g_j \cdot \propto_B \cdot m \cdot B \; ; \; m = -j, -j+1, \dots, j$$

Here μ_B is the Bohr magneton and g_j is the g factor. A high-frequency magnetic field with frequency f projected perpendicular to that magnetic field excites transitions between neighbouring energy states when they meet the resonance conditions

$$h \cdot f = E_{m+1} - E_m$$

(h = Planck's constant). This fact is the basis of electron spin resonance, in which the resonance signal is registered using high frequency technology. The electrons can often be considered as free. The subjects studied by electron spin resonance are the inner magnetic fields of the sample substance, which are generated by the magnetic moments of the neighbouring electrons and nuclei.

In experiment C3.4.4.1, electron spin resonance is demonstrated on diphenylpicrylhydrazyl (DPPH). DPPH is a radical in which a free electron occurs on a nitrogen atom. In the experiment, the resonance frequencies can be predefined continuously between 13 and 130 MHz. The aim of the assessment is to determine the g factor.





C3.5.1
POTENTIOMETRIC AND ACID-BASE TITRATIONS

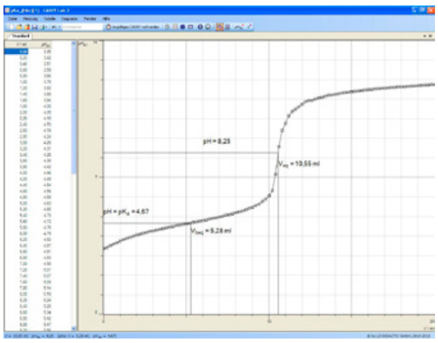
C3.5.1.1
Determination of acid concentration by titration with drop counter

Determination of acid concentration by titration with drop counter (C3.5.1.1)

Cat.-Nr.	Name	C3.5.1.1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
524 074	Timer S	1
337 4681	Drop counter	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	2
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
665 845	Burette, clear glass, 25 ml	1
665 816	Burette filling funnel, plastic, 25 mm diam.	1
666 559	Burette clamp for 1 burette, roller clamp	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm diam.	1
666 543	Double bosshead	2
666 555	Universal clamp, 0...80 mm	2
673 8420	Soda lye, 1 mol/l, 500 ml	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
	additionally required: balsamic vinegar or other dark coloured vinegar, PC with Windows XP/Vista/7/8	1

The classic technique for determining the exact quantity of a substance in solution (quantitative analysis) is titration. Here a reagent is slowly added in drops with a burette until the equivalence point is reached, i.e. the point at which the substance under investigation has reacted completely. In manual titrations, that point is made visible by means of a detection reagent, but it can also be measured by means of instrumentation.

In experiment C3.5.1.1, the acid concentration of balsamic vinegar is determined. Due to the dark colour, coloured indicators cannot be used here. Rather, the pH is measured continuously. This is done with a pH electrode. pH electrodes are potentiometric electrodes which respond ion-selectively only to changes in the potential of protons. The measured potential is then converted to a pH value. In the experiment, a complete titration curve of the titration of balsamic vinegar with sodium hydroxide is recorded using a drop counter.



Titration curve of vinegar





C3.5.2
CONDUCTOMETRIC TITRATIONS

C3.5.2.1
Conductometric titration of a hydrochloric acid solution

C3.5.2.2
Conductometric titration of a hydrochloric acid solution with pH measurement

Conductometric titration of a hydrochloric acid solution with pH measurement (C3.5.2.2)

Cat.-Nr.	Name	C3.5.2.1	C3.5.2.2
524 018	Pocket-CASSY 2 Bluetooth	1	
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*	
524 0031	Bluetooth dongle	1*	
524 220	CASSY Lab 2	1	1
524 0671	Conductivity adapter S	1	1
529 670	Conductivity sensor	1	1
607 105	Magnetic stirrer mini	1	1
664 103	Beaker, DURAN, 250 ml, squat	1	1
665 975	Bulb pipette, 10 ml, one mark	1	1
666 003	Pipetting ball	1	1
665 845	Burette, clear glass, 25 ml	1	1
665 816	Burette filling funnel, plastic, 25 mm diam.	1	1
666 559	Burette clamp for 1 burette, roller clamp	1	1
300 02	Stand base, V-shaped, small	1	1
300 42	Stand rod, 47 cm, 12 mm diam.	1	
666 543	Double bosshead	1	2
666 555	Universal clamp, 0...80 mm	1	2
674 6950	Hydrochloric acid, 0.1 mol/l, 500 ml	1	1
673 8410	Soda lye, 0.1 mol/l, 500ml	1	1
524 013	Sensor-CASSY 2		1
524 0672	pH adapter S		1
667 4172	pH sensor with plastic shaft, BNC		1
666 523	Stand rod, 450 x 12 mm diam., M10 thread		1
300 11	Saddle base		1
300 41	Stand rod, 25 cm, 12 mm diam.		1
674 4640	Buffer solution pH 4.00, 250 ml		1
674 4670	Buffer solution pH 7.00, 250 ml		1
	additionally required: PC with Windows XP/Vista/7/8	1	1

* additionally recommended

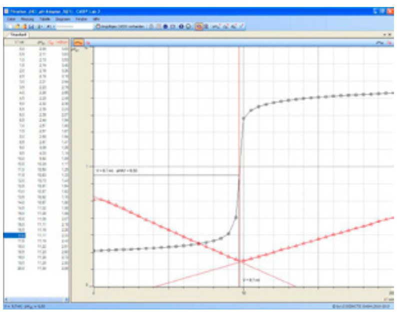
In conductometric titrations, the equivalence point is determined by measuring the conductivity. This technique relies on the fact that dissolved salts dramatically increase the conductivity of a solution. Acid-base titrations or precipitation titrations can be tracked conductometrically.

In experiment C3.5.2.1, an acid-base titration is performed in which a hydrochloric acid solution is titrated with sodium hydroxide. Because hydronium ions and hydroxide ions have very high conductivity, the equivalence point is easy to determine. During the titration, the conductivity falls at first because more and more hydronium ions are neutralised.

$$H_3O^+ + OH^- \rightleftharpoons 2\,H_2O$$

Beginning exactly from the equivalence point, it starts to rise again because then there is a surplus of hydroxide ions.

In experiment C3.5.2.2, along with conductivity, the change in pH is also traced. It becomes clear that the two measurement methods determine the same equivalence point. This is attributable to the fact that the same chemical process is measured in different ways.



Conductometric titration of hydrochloric acid





C3.5.3

REDOX TITRATIONS

C3.5.3.2
Manganometric determination of iron(II) ions

Manganometric determination of iron(II) ions (C3.5.3.2)

Cat.-Nr.	Name	C3.5.3.2
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 0672	pH adapter S	1
667 416	Single-rod redox probe, BNC	1
667 7977	Electronic Balance 200 : 0,01	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	2
300 42	Stand rod, 47 cm, 12 mm diam.	1
300 02	Stand base, V-shaped, small	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
665 845	Burette, clear glass, 25 ml	1
665 816	Burette filling funnel, plastic, 25 mm diam.	1
666 559	Burette clamp for 1 burette, roller clamp	1
666 543	Double bosshead	1
666 555	Universal clamp, 0...80 mm	1
671 9100	Iron(II)-sulfate-7-hydrate, 100 g	1
672 7000	Potassium permanganate, 100 g	1
674 7920	Sulfuric acid, diluted, approx. 2 N, 500 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1*
675 3500	Hydrogen peroxide, 30 %, 250 ml	1*
	additionally required: PC with Windows XP/Vista/7/8	1

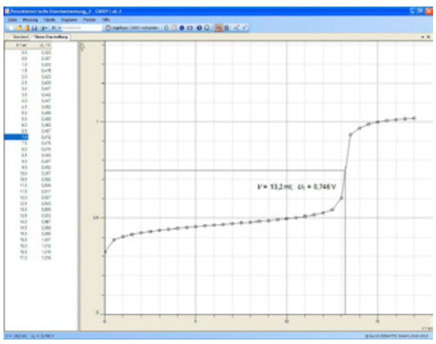
* additionally recommended

In redox titrations, a redox reaction takes place as an assay reaction. Similar to the pH indicator in acid-base titrations, the equivalence point is determined with redox indicators. Oxidation or reduction makes them change their colour at a specific „endpoint potential". Similar to the pH electrode, a redox electrode is used in the instrumental titration.

Manganometry requires no redox indicator because a potassium manganate solution is used as a reference solution. It has a deep violet colour and serves as an oxidising agent. In experiment C3.5.3.2, an iron(II) solution is titrated with a potassium permanganate solution.

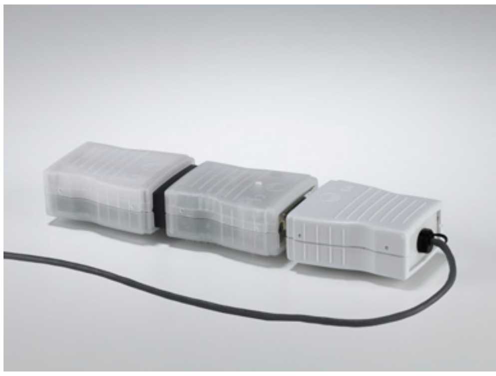
$$5\ Fe^{2+} + MnO_4^- + 8\ H^+ \rightleftharpoons 5\ Fe^{3+} + Mn^{2+} + 4\ H_2O$$

The endpoint is reached when the solution retains a constant violet colour. At the same time, a redox electrode is used to measure the potential of the solution.



Titration curve of a redox titration





C3.6.1
WATER ANALYTICS

C3.6.1.1
Determination of water contents with indicator reagents and immersion photometer

Determination of water contents with indicator reagents and immersion photometer (C3.6.1.1)

Cat.-Nr.	Name	C3.6.1.1
524 069	Immersion photometer S	1
666 2605	Holder for immersion photometer S	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
666 2600	Photometry - reagent set 1 (with storage case and accessories)	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 050	Test tube rack, plastic, for 9 tubes, 18 mm diam.	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
667 031ET10	Test tube holder, wooden, 20 mm diam., set of 10	1
656 016	Bunsen burner, universal	1
607 025	Safety gas hose 1.5 m	1
674 7860	Sulfuric acid, 95-98 %, 500 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The determination of water quality plays a role in many areas today. Not only drinking water and mineral water are analysed, but, for example, also swimming pools and lakes. Chemical and biological analyses can be carried out. In chemical water analytics, various ingredients are assayed. The concentrations of these substances indicate the quality of the water.

In experiment C3.6.1.1, water samples are tested for several ingredients, e.g. phosphate, ammonium or nitrate. These are photometric assays. The chemical basis for this relies on the fact that the ingredient to be identified forms a coloured compound or turbidity with the reagents added. At an appropriate wavelength, the extinction of the colour or turbidity created in this way is directly proportional to the concentration of the ingredient.



Continuous measurement of carbon dioxide concentration in the classroom (C3.6.2.1)

C3.6.2
AIR ANALYTICS

C3.6.2.1
Continuous measurement of carbon dioxide concentration in the classroom

Cat.-Nr.	Name	C3.6.2.1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 083	CO_2 sensor S	1
501 11	Extension cable, 15 pin	1*
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	2
	additionally required: PC with Windows XP/Vista/7/8	1

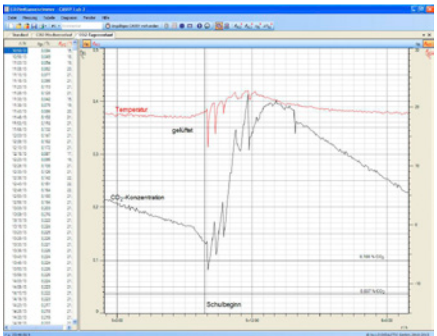
* additionally recommended

The air all around us contains mainly nitrogen and oxygen. But the other substances, the ones which occur in significantly lower concentrations - in the ppm range (ppm = parts per million) or even less - are precisely the ones which can be harmful to humans. These are studied in air analyses.

One of the challenges here is the low concentration of the substances. In addition, the analysis of gases requires more complex instrumentation and is less easily accessible than the analysis of liquids.

In this context, it is worthwhile to study the interiors of classrooms or seminar rooms, where it is particularly important to maintain optimal air conditions, in order to facilitate the learning process.

In experiment C3.6.2.1, the carbon dioxide concentration in the classroom is studied for a period of one week. At the same time, the temperature is measured at two positions, e.g. on the radiator and in the classroom. In a room full of people, the CO_2 concentration rises rapidly above 1 %, and simply letting some air in can hardly lower it to the value in the atmosphere.



Carbon dioxide values in a class room



Analysis of cigarette smoke (C3.6.2.2)

C3.6.2
AIR ANALYTICS

C3.6.2.2
Analysis of cigarette smoke

Cat.-Nr.	Name	C3.6.2.2
665 914	Gas syringe, 100 ml with 3-way stopcock	3
665 255	Three-way valve, T-shaped, ST nozzles	1
667 312	Glass connector S, 2 x GL 18	3
666 313	Testing tube for NO_x, 0.5...50 ppm, set of 10	1
666 319	Testing tube for CO, 0.5...7.0 %, set of 10	1
666 314	Testing tube for SO_2, 1...25 ppm, set of 10	1
667 015	Glass file, triganular	1

Smoke from cigarette tobacco contains not only nicotine, but also many toxic substances, including nitrogen oxides, tar and formaldehyde. In experiment C3.6.2.2, cigarette smoke is analysed for various airborne toxic substances. In so doing, different cigarette brands and strengths can be compared.





C3.6.4
FOOD ANALYTICS

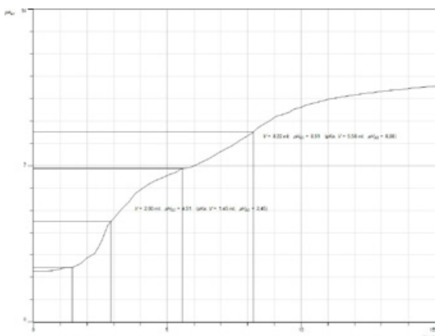
C3.6.4.2
Determination of the content of phosphoric acid in a cola drink

Determination of the content of phosphoric acid in a cola drink (C3.6.4.2)

Cat.-Nr.	Name	C3.6.4.2
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
529 672	pH sensor, BNC	1
524 074	Timer S	1
337 4681	Drop counter	1
664 131	Beaker, Boro3.3, 400 ml, squat	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
665 845	Burette, clear glass, 25 ml	1
666 559	Burette clamp for 1 burette, roller clamp	1
301 09	Bosshead S	2
666 555	Universal clamp, 0...80 mm	1
607 105	Magnetic stirrer mini	1
300 02	Stand base, V-shaped, small	1
300 11	Saddle base	1
301 26	Stand rod, 25 cm, 10 mm diam.	1
301 27	Stand rod, 50 cm, 10 mm diam.	1
661 243	Wash bottle, PE, 500 ml	1
673 8421	Soda lye, 1 mol/l, 1 l	1
	additionally required: Cola beverage	1

As an applied science, food analytics forms the basis for the study and assessment of the quality and safety of food.

Phosphoric acid is added to cola in order to heighten the sensation of thirst, as a preservative, and to cover up the sugary taste. In experiment C3.6.4.2, phosphoric acid is titrated with sodium hydroxide. When titrating cola, the first two buffer stages are also clearly recognisable, just as in the titration of phosphoric acid. (It is generally impossible to titrate the third stage in these diluted solutions.) The second stage becomes indistinct in the presence of other ingredients. The phosphoric acid content of the cola beverage can be determined with the first stage.



Titration of a cola drink





C3.6.5
MATERIAL ANALYTICS

C3.6.5.1
X-ray fluorescence analysis of chemical composition

C3.6.5.2
The chemical composition of a brass specimen

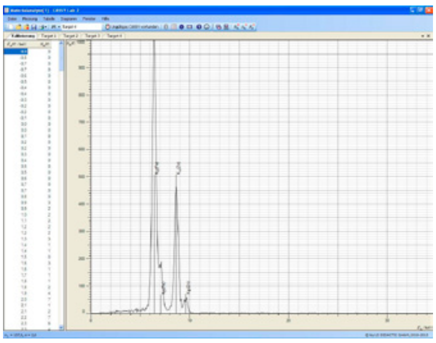
X-ray fluorescence analysis of chemical composition (C3.6.5.1)

Cat.-Nr.	Name	C3.6.5.1	C3.6.5.2
554 800	X-ray apparatus	1	1
554 861	X-ray tube, Mo	1	1
554 831	Goniometer	1	1
559 938	X-ray energy detector	1	1
554 848	Set of target alloys	1	1
524 018	Pocket-CASSY 2 Bluetooth	1	1
524 058	MCA box	1	1
524 220	CASSY Lab 2	1	1
501 02	BNC cable, 1 m	1	1
554 844	Set of targets for K-line fluorescence		1
554 846	Set of targets for L-line fluorescence		1
	additionally required: PC with Windows XP/Vista/7/8	1	1

X-ray fluorescence is a method for the non-destructive analysis of the chemical composition of an alloy. Under exposure to X-rays, each of the individual elements emits characteristic X-ray fluorescence, which identifies the element like a fingerprint.

In experiment C3.6.5.1, four alloys are analyzed by means of X-ray fluorescence and the composition is determined qualitatively. The alloys are chrome-nickel steel, two brass alloys and a rare earth magnet.

In experiment C3.6.5.2, the composition of a brass alloy is analysed quantitatively. The weight percents of each component are calculated from the strength of the X-ray fluorescence.



Analysis of alloys

C4 PHYSICAL CHEMISTRY





C4.1.1
CATALYSIS

C4.1.1.1
Catalytic oxidation of tartaric acid with hydrogen peroxide

Catalytic oxidation of tartaric acid with hydrogen peroxide (C4.1.1.1)

Cat.-Nr.	Name	C4.1.1.1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 416	Single-rod redox probe, BNC	1
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
667 7977	Electronic Balance 200 : 0,01	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
666 8451	Magnetic stirrer	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
666 859	Stirring bar retriever	1
666 502	Bunsen burner stand, 450 mm high	1
301 09	Bosshead S	2
666 555	Universal clamp, 0...80 mm	2
672 6710	Potassium sodium tartrate, 250 g	1
675 3500	Hydrogen peroxide, 30 %, 250 ml	1
672 8000	Cobalt(II)-chloride-6-hydrate, 25 g	1
	additionally required: PC with Windows XP/Vista/7/8	1

The rate of a reaction is defined as the change in concentration over time. For the reaction

$$A + B \rightleftharpoons C$$

therefore, the following applies:

$$v_A = -\frac{d[A]}{dt}; v_B = -\frac{d[B]}{dt}; v_C = \frac{d[C]}{dt}$$

One challenge in analyses of this type is to continuously measure the concentration of one of the participants in the reaction. This is possible with reactions in which one or more participants in the reaction change colour or oxidation level, or in which salts form (increase in conductivity).

Apart from elevating the concentration and temperature, the rate of reactions can also be increased by the addition of catalysts. Because catalysts are not consumed in a reaction, a small amount is already enough to enable the conversion of large quantities of the reacting substances.

In experiment C4.1.1.1, hydrogen peroxide is used to convert tartaric acid oxidatively to CO_2 and H_2O under catalysis. The catalyst cobalt(II) chloride hexahydrate speeds up the reaction, but does not participate in the transformation and remains unchanged once the process has been completed. The reaction is monitored by measuring the redox potential and the temperature.





C4.1.2
REACTION ORDERS

C4.1.2.1
Hydrolysis of tertiary butyl chloride

C4.1.2.2
Determination of the reaction order of the reaction of malachite green with hydroxide ions

Hydrolysis of tertiary butyl chloride (C4.1.2.1)

Cat.-Nr.	Name	C4.1.2.1	C4.1.2.2
524 018	Pocket-CASSY 2 Bluetooth	1	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*	1*
524 0031	Bluetooth dongle	1*	1*
524 220	CASSY Lab 2	1	1
524 0671	Conductivity adapter S	1	
529 670	Conductivity sensor	1	
607 105	Magnetic stirrer mini	1	1
664 103	Beaker, DURAN, 250 ml, squat	1	3
300 11	Saddle base	1	1
301 26	Stand rod, 25 cm, 10 mm diam.	1	
301 09	Bosshead S	1	
666 555	Universal clamp, 0...80 mm	1	1
665 754	Measuring cylinder, 100 ml, with plastic base	1	
665 994	Graduated pipette, 1 ml	1	
666 003	Pipetting ball	1	1
671 1450	Tertiary butyl chloride, 100 ml	1	
670 0400	Acetone, 250 ml	1	
524 069	Immersion photometer S		1
666 851	Stirring magnet, 25 mm x 6 mm diam.		1
665 756	Measuring cylinder, 500 ml, with plastic base		1
665 755	Measuring cylinder, 250 ml, with plastic base		1
665 753	Measuring cylinder, 50 ml, with plastic base		1
667 7988	Analytical balance ABS 80-4, 83:0.0001 g		1
665 793	Volumetric flask, Boro 3.3, 100 ml		1
665 997	Graduated pipette, 10 ml		1
602 347	Laboratory bottle, 500 ml, GL 45 thread		1
300 41	Stand rod, 25 cm, 12 mm diam.		1
666 543	Double bosshead		1
661 243	Wash bottle, PE, 500 ml		1
673 1670	Malachite green, 25 g		1
671 9720	Ethanol, denaturated, 1 l		1
673 6800	Sodium hydroxide, 100 g		1
675 3400	Water, pure, 1 l		1
	additionally required: PC with Windows XP/Vista/7/8	1	1

* additionally recommended

The reaction order can be used to test hypotheses about the stepwise course of reactions. The reaction order must be determined experimentally. In order to do so, a diagram is drawn showing of the rate of reaction versus the respective concentration. If the resulting curve is a straight line, then it represents a first-order reaction. A parabola indicates a second-order reaction.

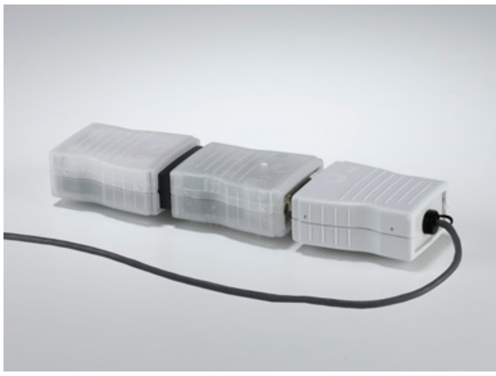
In experiment C4.1.2.1, the hydrolysis of tertiary butylchloride (2-chloro-2-methylpropane) generates tertiary butanol and hydrochloric acid (HCl). In this protolysis reaction, HCl forms hydronium and chloride ions, which cause a strong increase in conductivity:

$$(CH_3)_3\text{-}Cl + 2\,H_2O \rightarrow (CH_3)_3C\text{-}OH + H_3O^+ + Cl^-$$

The change in conductivity and the concentration of the butylchloride are used to determine the reaction order.

In Experiment C4.1.2.2 malachite green is bleached using sodium hydroxide solution. This bleaching can be followed with an immersion photomoeter. This way, the half time, the reaction order and, based on these data, the reaction rate constant can be determined.





C4.1.3
INFLUENCING THE RATE OF REACTION

C4.1.3.1
Reaction of malachite green with hydroxide ions

Reaction of malachite green with hydroxide ions (C4.1.3.1)

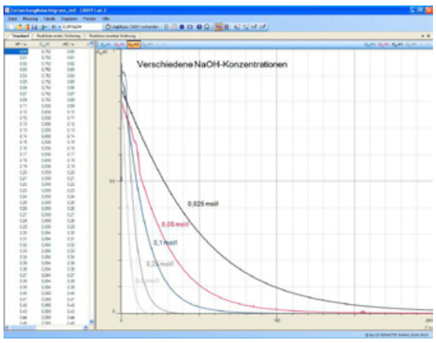
Cat.-Nr.	Name	C4.1.3.1
524 069	Immersion photometer S	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
607 105	Magnetic stirrer mini	1
666 851	Stirring magnet, 25 mm x 6 mm diam.	4
664 103	Beaker, DURAN, 250 ml, squat	4
665 756	Measuring cylinder, 500 ml, with plastic base	1
665 755	Measuring cylinder, 250 ml, with plastic base	1
665 753	Measuring cylinder, 50 ml, with plastic base	1
667 7988	Analytical balance ABS 80-4, 83:0.0001 g	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
602 347	Laboratory bottle, 500 ml, GL 45 thread	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm diam.	1
666 543	Double bosshead	1
666 555	Universal clamp, 0...80 mm	1
661 243	Wash bottle, PE, 500 ml	1
673 1670	Malachite green, 25 g	1
671 9720	Ethanol, denaturated, 1 l	1
673 6800	Sodium hydroxide, 100 g	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The rate of a reaction can be affected by many parameters. These include the temperature and the concentration of the substance involved. The choice of solvent can also play a role.

Reactions in which a participant in the reaction changes colour are a suitable choice if one wishes to observe the course of a reaction. Such reactions are easy to track photometrically, because the decrease and increase in the extinction rate can be directly converted mathematically into concentration changes.

In experiment C4.1.3.1, the reaction of malachite green with hydroxide ions is monitored with an immersion photometer in a glass beaker. Blue-green at first, the solution loses colour when sodium hydroxide is added. This simple system makes it possible to investigate how the rate of reaction is affected by temperature, concentration and the choice of solvent.



Reaction of malachite green with sodium hydroxide solution



Influencing the equilibrium (C4.2.1.1)

C4.2.1
LAW OF MASS ACTION

C4.2.1.1
Influencing the equilibrium

Cat.-Nr.	Name	C4.2.1.1
664 268	Flat-bottom flask, DURAN, 250 ml, wide neck	3
664 249	Erlenmeyer flask, Boro 3.3, 100 ml, narrow neck	2
604 5681	Powder spatula, steel, 150 mm	1
667 7977	Electronic Balance 200 : 0,01	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
666 854	Stirring magnet, 50 mm x 8 mm diam.	1
607 105	Magnetic stirrer mini	1
665 996	Graduated pipette, 5 ml	2
666 003	Pipetting ball	1
665 009	Funnel, PP, 75 mm diam.	1
666 859	Stirring bar retriever	1
671 8710	Iron(III)-chloride-6-hydrate, 250 g	1
672 7400	Potassium thiocyanate, 100 g	1

One of the most important laws in chemistry is the law of mass action. It provides insight into the mechanism of chemical reactions while also offering the chemist the ability to affect a chemical reaction in a way that favours the creation of specifically intended molecules. The law of mass action states that in a chemical reaction the concentration of the starting materials remains in an absolutely constant proportion to the concentration of the final materials.

Experiment C4.2.1.1 studies the chemical equilibrium of the reaction of thiocyanate with iron. The chemical equilibrium is a dynamic equilibrium in which the starting materials and final products are present alongside one another in the reaction mixture. Under equilibrium conditions, exactly so many parts react in one direction as back in the opposite direction. In so doing, the concentrations of the participants in the reaction remain constant and their quotient is expressed as the equilibrium constant K. By adding one of the substances involved, a new equilibrium is established.

For the reaction being investigated here

$$Fe^{3+} + 3\,SCN^{-} \rightleftharpoons Fe(SCN)_3$$

the equilibrium constant can be calculated as follows:

$$\frac{[Fe(SCN)_3]}{[Fe^{3+}]\cdot[SCN^{-}]^3} = K$$

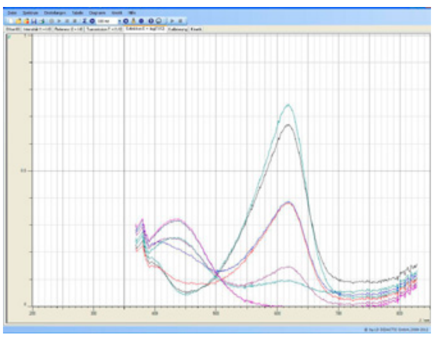


C4.2.2
PROTOLYSIS EQUILIBRIUM

C4.2.2.1
Determination of the acidity constant of bromothymol blue

Determination of the acidity constant of bromothymol blue (C4.2.2.1)

Cat.-Nr.	Name	C4.2.2.1
467 252	Compact spectrometer, complete	1
664 470	Rectangular cuvette cell, glass, 10 x 10 mm	2
665 996	Graduated pipette, 5 ml	2
666 003	Pipetting ball	1
602 345	Laboratory bottle, 100 ml, GL 45 thread	5
665 793	Volumetric flask, Boro 3.3, 100 ml	2
667 7977	Electronic Balance 200 : 0,01	1
667 4781	Digital pH-Meter 201	1
674 4600	Buffer solution set, 250 ml	1
671 0800	Bromothymol blue solution, 0.1 %, 50 ml	1
674 6950	Hydrochloric acid, 0.1 mol/l, 500 ml	1
673 8410	Soda lye, 0.1 mol/l, 500ml	1
673 6710	Sodium acid phosphate, 250 g	1
673 6010	Sodium dihydrogenphosphate, 250 g	1
	additionally required: PC with Windows XP/Vista/7/8	1



Spectra of bromthymol blue solutions at different pH values

The reaction of acids (AH) with water - protolysis - is an equilibrium reaction.

$$AH + H_2O \rightleftharpoons A^- + H_3O^+$$

The equilibrium constant K_a, also known as the acid dissociation constant, is a measure of the strength of an acid.

$$K = \frac{[H_3O^+]\cdot[A^-]}{[HA]\cdot[H_2O]}; K_a = K\cdot[H_2O] = \frac{[H_3O^+]\cdot[A^-]}{[HA]}$$

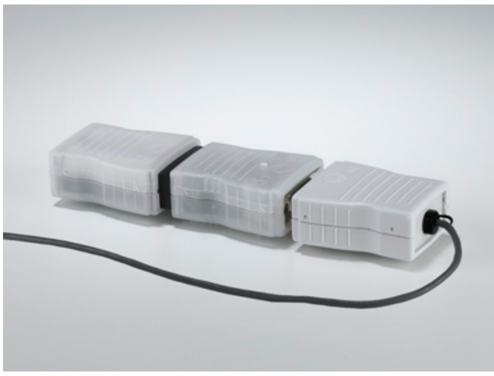
It indicates the magnitude of the ratio between the protonated and non-protonated form of the acid. In most cases, however, the pK_a value, i.e. the negative base 10 logarithm of the acid dissociation constant, is given.

In experiment C4.2.2.1, the pH-dependent colour of the indicator bromothymol blue is used to determine the pKa value of the dye. The colouration enables the simultaneous determination of the concentration of the protonated (yellow) and non-protonated (blue) form of the indicator, with which, in turn, the Henderson-Hasselbalch equation

$$pH = pKs + \log_{10}\left(\frac{[A^-]}{[HA]}\right)$$

can be used to compute the pKa value.





C4.3.1
ENTHALPY OF CHEMICAL REACTIONS

C4.3.1.1
Differentiating between endothermic and exothermic reactions

Differentiating between endothermic and exothermic reactions (C4.3.1.1)

Cat.-Nr.	Name	C4.3.1.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 044	Temperature sensor S, NTC	1
300 02	Stand base, V-shaped, small	1
301 27	Stand rod, 50 cm, 10 mm diam.	1
301 09	Bosshead S	2
666 555	Universal clamp, 0...80 mm	2
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 053	Test tube rack, for 10 tubes, 22 mm diam.	1
667 031ET10	Test tube holder, wooden, 20 mm diam., set of 10	1
604 5661	Spatula, double ended, 185 mm	1
656 017	Teclu burner, universal	1
667 187	Safety gas hose with end clamp, 1 m	1
661 243	Wash bottle, PE, 500 ml	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1
	additionally required: PC with Windows XP/Vista/7/8	

* additionally recommended

Every chemical reaction is characterised by a transformation of material. That transformation is closely connected with an energy transformation and/or energy change. In this way, heat energy is either consumed or heat is created, i.e. the reaction proceeds endothermically or exothermically.

In experiment C4.3.1.1, copper(II) sulfate in the pentahydrate form and in the anhydrous form is used to demonstrate the principle of endothermic and exothermic reactions. Here the reaction of copper(II) sulfate-5-hydrate under high heat to anhydrous copper(II) sulfate represents the endothermic reaction. The anhydrous copper(II) sulfate obtained in this way reacts in turn with water while generating heat, thereby demonstrating an exothermic reaction.

$$\underset{\text{(blue)}}{CuSO_4 \times 5\,H_2O} \rightleftharpoons \underset{\text{(white)}}{CuSO_4} + 5\,H_2O$$





C4.3.3
CALORIMETRY

C4.3.3.1
Determination of the heat of combustion of benzoic acid

Determination of the heat of combustion of benzoic acid (C4.3.3.1b)

Cat.-Nr.	Name	C4.3.3.1a	C4.3.3.1b
666 429	Calorimeter for solids and liquids, CPS	1	
664 800	Gas scrubber bottle, lower section, 200 ml	2	2
664 805	Glass tube insert, ST 29/32	2	2
531 836	Universal measuring instrument, Chemistry	1	1
524 044	Temperature sensor S, NTC	1	1
667 312	Glass connector, 2 x GL 18	1	
667 180	Rubber tubing, 1 m x 7 mm diam., DIN 12865	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
604 510	Hose connector, 4...15 mm	1	1
521 546	DC Power Supply 0 ... 16 V, 0 ... 5 A	1	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1	1
660 998	Minican pressurised gas canister, oxygen	1	1
660 980	Fine regulating valve for minican gas canisters	1	1
667 7977	Electronic Balance 200 : 0,01	1	1
666 428	Panel frame C100, two-level, for CPS	1	
666 4660	Adhesive magnetic board, 300 mm	2	
666 4664	Spring clips, magnetic, size 6a, 27...29 mm	2	
301 312	Console	1	
726 21	Equipment platform, 350 mm	1	
670 8300	Benzoic acid, 50 g	1	1
667 325	Calorimeter for solids and liquids		1
666 603	Base rail, 95 cm		1
301 09	Bosshead S		3
666 615	Universal bosshead		3
301 72	Universal clamp, 0...120 mm		1
666 555	Universal clamp, 0...80 mm		2
301 27	Stand rod, 50 cm, 10 mm diam.		3
	additionally required: PC with Windows XP/Vista/7/8	1	1

The term ‚calorimetry' refers to the measurement of quantities of heat which are linked to biological, chemical or physical processes. They can be both exothermic and endothermic. Quantities of heat are determined by means of calorimeters.

In experiment C4.3.3.1, the temperature rise in the demonstration calorimeter is measured while burning benzoic acid. The substance is weighed before and after the combustion process. The combustion takes place in an oxygen atmosphere, whereby ignition is initiated by a filament. The energy released is calculated using either a previously determined heat capacity of the filled calorimeter or the individual theoretical values of the heat capacities of the glass jacket and calorimeter liquid. The quantity of heat Q is calculated according to the following formula:

$$Q = \Delta T \times (m_k \times C_k + m(H_2O) \times C(H_2O))$$

Here ΔT is the measured temperature difference, m_k and $m(H_2O)$ are the mass of the calorimeter and of the water and C_k and $C(H_2O)$ is the heat capacity of the glass apparatus and the water. In order to calculate the heat of combustion ΔH, the ignition energy, which also contributed to the heating of the apparatus, must be subtracted and the quantity of heat must be expressed relative to one mol of substance.

Variant (a) is set up in a chemistry board system frame and variant (b) is set up on a base rail.





C4.3.3
CALORIMETRY

C4.3.3.3
Determination of the enthalpy of neutralisation of acids and alkali solutions

Determination of the enthalpy of neutralisation of acids and alkali solutions (C4.3.3.3)

Cat.-Nr.	Name	C4.3.3.3
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
607 105	Magnetic stirrer mini	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
602 023	Beaker, Boro 3.3, 150 ml, squat	3
665 753	Measuring cylinder, 50 ml, with plastic base	2
300 11	Saddle base	1
301 26	Stand rod, 25 cm, 10 mm diam.	1
301 09	Bosshead S	1
673 8400	Soda lye, diluted, 500 ml	1
673 8420	Soda lye, 1 mol/l, 500 ml	1
674 6920	Hydrochloric acid, approx. 2 mol/l, 500ml	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1
671 9550	Acetic acid, dil., (approx. 2 mol/l), 500 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

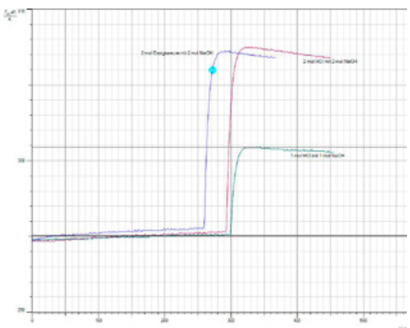
When strong acids and strong alkalis react with one another, energy is given off to the surroundings in the form of heat - the so-called ‚heat of neutralisation'.

In experiment C4.3.3.3, measured quantities of hydrochloric acid and sodium hydroxide at the same temperature are neutralised together. The temperature increase ΔT is measured and from that result the quantity of heat Q_P is calculated:

$$Q_P = \Delta T \times \left(C_{H_2O} \times m + C_k \right)$$

From the quantity of heat, the following equation can be used to calculate the molar heat of neutralisation $\Delta_R H_m$:

$$\Delta_R H_m = \frac{Q_P}{n}$$



Determination of the enthalpy of neutralisation





C4.3.3
CALORIMETRY

C4.3.3.4
Determination of enthalpy of mixing

Determination of enthalpy of mixing (C4.3.3.4)

Cat.-Nr.	Name	C4.3.3.4
524 018	Pocket-CASSY 2 Bluetooth	1
524 0031	Bluetooth dongle	1*
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 220	CASSY Lab 2	1
386 40	Dewar flask, clear, for demonstration	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
524 0673	NiCr-Ni adapter S, type K	1
664 155	Watch glass dish, 100 mm diam.	1
607 105	Magnetic stirrer mini	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
300 11	Saddle base	1
301 26	Stand rod, 25 cm, 10 mm diam.	1
301 09	Bosshead S	1
602 953	Measuring cylinder, Boro 3.3, 100 ml, glass base	1
665 994	Graduated pipette, 1 ml	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
670 0410	Acetone, 1 l	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

When two substances A and B are mixed together without initiating a chemical reaction, heats of mixing are released or consumed. If the mixing process takes place at constant pressure, the heat of mixing is equal to the enthalpy of mixing.

The cause of the enthalpy of mixing lies in the differences of the interaction energies of the similar molecules in the pure components along with the interaction energy between the different types of molecules in the mixture. If the interaction between similar molecules is stronger than between dissimilar ones, the mixing requires energy, so the solution cools down. In the opposite case, the solution warms up.

Experiment C4.3.3.4 determines the enthalpy of mixing of two solutions with different concentrations and measures the heat of mixing released.



Ion transport in liquids (C4.4.1.1)

C4.4.1
CONDUCTIVITY AND IONS

C4.4.1.1
Ion transport in liquids

Cat.-Nr.	Name	C4.4.1.1
664 091	Double U-tube, 160 mm, with 2 G4 filters	1
664 369	Platinum leaf rod electrodes, set of 2	1
664 4071	Electrochemistry demonstration unit, CPS	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
591 21	Clip plug, large	2
665 754	Measuring cylinder, 100 ml, with plastic base	1
665 753	Measuring cylinder, 50 ml, with plastic base	1
665 752	Measuring cylinder, 25 ml, with plastic base	1
602 022	Beaker, Boro 3.3, 100 ml, squat	2
664 130	Beaker, Boro3.3, 250 ml, squat	1
665 217	Glass stirring rod, 500 mm x 8 mm diam., set of 10	3
604 5682	Powder spatula, steel, 185 mm	1
667 297	Silicone gaskets, GL 25/8, set of 10	1
667 255	Rubber stopper, solid, 16...21 mm diam.	1
667 7977	Electronic Balance 200 : 0,01	1
670 4910	Ammonium sulfate, 500 g	1
672 7000	Potassium permanganate, 100 g	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1
670 3600	Ammonia solution, 25 %, 250 ml	1
675 3500	Hydrogen peroxide, 30 %, 250 ml	1
674 6691	Nitric acid, 1 mol/l, 1 l	1

Unlike solids, in which current is transported via electrons (1^{st} order conductor), liquids can transport charges only via ions (2^{nd} order conductor). The conductivity depends on both the number and the mobility of the ions present in the solution.

Conductivity relies on the migration of ions in the electric field. Anions (negative) migrate to the positive pole, cations (positive) migrate to the negative pole.

In experiment C4.4.1.1, this migration is observed directly. The coloured anion permanganate (MnO_4^-) and the coloured cation copper tetraammine ($Cu(NH_3)_4^{2+}$) are used for this purpose. In this way, the direction of migration and the magnitude of the speed can be determined.



Determination of migration velocity of permanganate ions (C4.4.1.2)

C4.4.1
CONDUCTIVITY AND IONS

C4.4.1.2
Determination of migration velocity of permanganate ions

Cat.-Nr.	Name	C4.4.1.2
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 243	Erlenmeyer flask, 100 ml, narrow neck, SB 19	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
664 101	Beaker, DURAN, 100 ml, squat	1
665 212ET10	Glass stirring rod, 200 mm x 8 mm diam., set of 10	1
604 5682	Powder spatula, steel, 185 mm	1
666 8471	Magnetic stirrer with hotplate	1
602 725	Laboratory dish, 140 mm diam., 900 ml	1
667 7977	Electronic Balance 200 : 0,01	1
672 6800	Potassium nitrate, 100 g	1
672 7000	Potassium permanganate, 100 g	1
670 1600	Agar-Agar, 50 g	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1
675 3500	Hydrogen peroxide, 30 %, 250 ml	1

In a solution ions migrate toward the oppositely charged pole. The speed of migration depends on many factors, including the size and hydration of the ions.

Experiment C4.4.1.2 determines the speed of migration of permanganate ions.



Determination of specific conductivity (C4.4.1.3)

C4.4.1
CONDUCTIVITY AND IONS

C4.4.1.3
Determination of specific conductivity

Cat.-Nr.	Name	C4.4.1.3
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
604 5682	Powder spatula, steel, 185 mm	1
665 212ET10	Glass stirring rod, 200 mm x 8 mm diam., set of 10	1

The conductivity of a solution depends on the type and quantity of the dissolved ions. Every type of ion has a specific conductivity κ, which is the reciprocal of the specific resistance ς. The conductivity depends on the length of the conductor (electrode distance) l and on the cross-sectional area of the electrodes q according to the following formular:

$$\kappa = \frac{1}{\varsigma} = \frac{1}{R} \cdot \frac{l}{q}$$

Experiment C4.4.1.3 determines the specific conductivity of tap water. The effect of electrode distance on conductivity can also be investigated.





C4.4.1
CONDUCTIVITY AND IONS

C4.4.1.4
Electrolytic dissociation:
Dependence of conductivity
on electrolyte concentration

Electrolytic dissociation: Dependence of conductivity on electrolyte concentration (C4.4.1.4)

Cat.-Nr.	Name	C4.4.1.4
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 0671	Conductivity adapter S	1
529 670	Conductivity sensor	1
665 792	Volumetric flask, Boro 3.3, 50 ml	1
665 845	Burette, clear glass, 25 ml	2
664 103	Beaker, DURAN, 250 ml, squat	2
607 105	Magnetic stirrer mini	1
604 591	Stirring magnet, PTFE, oval, l = 30 mm	1
667 7988	Analytical balance ABS 80-4, 83:0.0001 g	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp, 0...80 mm	1
666 559	Burette clamp for 1 burette, roller clamp	1
665 816	Burette filling funnel, plastic, 25 mm diam.	1
671 9560	Acetic acid, 0.1 mol/l, 500ml	1
672 5200	Potassium chloride, 100 g	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

The conductivity of a solution is concentration-dependent. A distinction is drawn between strong and weak electrolytes. While strong electrolytes are completely dissociated, the dissociation of weak electrolytes is highly concentration-dependent.

In experiment C4.4.1.4, this behaviour is investigated in potassium chloride and acetic acid, and among other things the equivalent conductivity is determined.



The electrochemical series (C4.4.3.1_a)

C4.4.3
ELECTROCHEMICAL POTENTIALS

C4.4.3.1a
The electrochemical series

Cat.-Nr.	Name	C4.4.3.1 (a)
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
667 7977	Electronic Balance 200 : 0,01	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1
675 5410	Zinc sulfate-7-hydrate, 250 g	1
674 8610	Silver nitrate, 25 g	1
670 9650	Lead nitrate solution, 500 ml	1*
671 9110	Iron(II)-sulfate-7-hydrate, 250 g	1
673 9000	Nickel(II)-sulfate, 100 g	1*

* additionally recommended

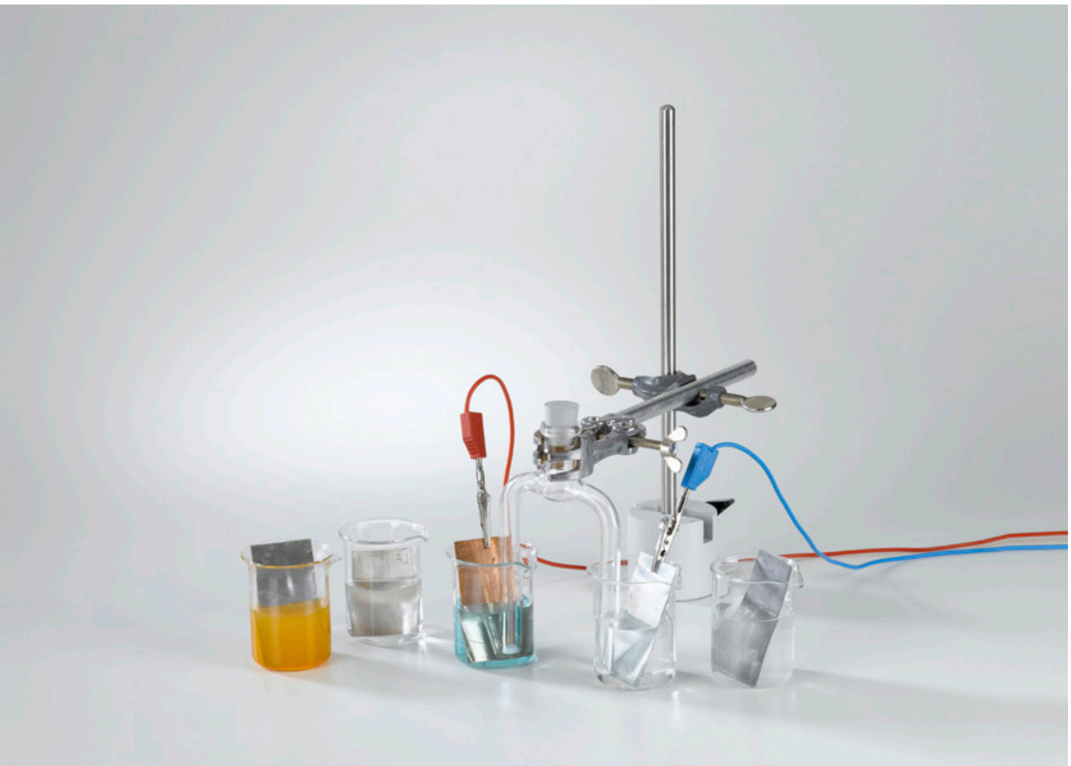
If a metal M is immersed in a solution of its ions M^{n+}, then its dissolution and deposition tendency creates a potential.

$$M \rightleftharpoons M^{n+} + n\,e^-$$

A measurable potential difference occurs only after two different of such half-cells are combined to form a galvanic cell (voltage, electromotive force EMF).

There are noble and base metals. This property depends on the potential of the half-cell of a metal. In experiment C4.4.3.1, voltage measurements on combinations of different metals are used to create an electromotive series of the metals. In so doing, the noblest or basest half-cell can serve as reference point.

The experiment can be carried out in two variants: In variant C4.4.3.1 (a) the experiment is carried out with the demonstration unit for electrochemistry and in variant C4.4.3.1 (b) the experiment is carried out with a salt bridge.





C4.4.3 ELECTROCHEMICAL POTENTIALS

C4.4.3.1b The electrochemical series with salt bridge

The electrochemical series with salt bridge (C4.4.3.1_b)

Cat.-Nr.	Name	C4.4.3.1 (b)
531 836	Universal measuring instrument, Chemistry	1
524 0621	UIP sensor S	1
664 137	Beaker, Boro3.3, 100 ml, tall	6
665 754	Measuring cylinder, 100 ml, with plastic base	1
667 455	Salt bridge, 90 mm x 90 mm, 20 mm diam.	1
667 255	Rubber stopper, solid, 16...21 mm diam.	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
501 861	Crocodile-clips, polished, set of 6	1
667 7977	Electronic Balance 200 : 0,01	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp, 0...80 mm	1
604 5682	Powder spatula, steel, 185 mm	1
672 5200	Potassium chloride, 100 g	1
591 53	Plate electrodes, copper, 76x40 mm, set of 10	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1
591 54	Plate electrodes, zinc, 76x40 mm, set of 10	1
675 5410	Zinc sulfate-7-hydrate, 250 g	1
664 421	Plate electrodes, silver, 55 x 40 mm, set of 2	1
674 8610	Silver nitrate, 25 g	1
591 55	Plate electrodes, iron, 76x40 mm, set of 10	1
671 9110	Iron(II)-sulfate-7-hydrate, 250 g	1
591 56	Plate electrodes, nickel, 76x40 mm, set of 5	1*
673 9000	Nickel(II)-sulfate, 100 g	1*
591 591	Plate electrodes, lead, 76x40 mm, set of 2	1*
670 9650	Lead nitrate solution, 500 ml	1*

* additionally recommended

If a metal M is immersed in a solution of its ions M^{n+}, then its dissolution and deposition tendency creates a potential.

$$M \rightleftharpoons M^{n+} + n\,e^-$$

A measurable potential difference occurs only after two different of such half-cells are combined to form a galvanic cell (voltage, electromotive force EMF).

There are noble and base metals. This property depends on the potential of the half-cell of a metal. In experiment C4.4.3.1, voltage measurements on combinations of different metals are used to create an electromotive series of the metals. In so doing, the noblest or basest half-cell can serve as reference point.

The experiment can be carried out in two variants: In variant C4.4.3.1 (a) the experiment is carried out with the demonstration unit for electrochemistry and in variant C4.4.3.1 (b) the experiment is carried out with a salt bridge.



Standard potentials of metals (C4.4.3.2_a)

C4.4.3
ELECTROCHEMICAL POTENTIALS

C4.4.3.2
Standard potentials of metals

Cat.-Nr.	Name	C4.4.3.2 (a)	C4.4.3.2 (b)
664 4071	Electrochemistry demonstration unit, CPS	1	
664 401	Electrochemistry accessories set	1	
666 425	Panel frame C50, two-level, for CPS	1	
666 472	Table for electrochemistry, CPS	1	
664 111	Beaker, DURAN, 100 ml, tall	1	2
667 7977	Electronic Balance 200 : 0,01	1	1
665 754	Measuring cylinder, 100 ml, with plastic base	1	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1	1
675 5410	Zinc sulfate-7-hydrate, 250 g	1	1
674 6910	Hydrochloric acid, 1 mol/l, 1 l	1	
672 1901	Hexacloroplatinic acid, 5 g	1	
664 412	Standard hydrogen electrode HydroFlex		1
531 836	Universal measuring instrument, Chemistry		1
524 0621	UIP sensor S		1
591 53	Plate electrodes, copper, 76x40 mm, set of 10		1
591 54	Plate electrodes, zinc, 76x40 mm, set of 10		1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair		1
501 861	Crocodile-clips, polished, set of 6		1

To determine the potential of a half-cell, a reference parameter is necessary. By international agreement, the half-cell H_2/H_3O^+ has been established as reference cell. That standard hydrogen electrode has been arbitrarily assigned the potential $E_0 = 0.00$ V.

In experiment C4.4.3.2, a standard hydrogen electrode is used to measure the standard potentials of various metals. This can be done either with the demonstration unit for electrochemistry (experiment C4.4.3.2 (a)) or with the Universal measuring instrument, Chemistry and the prefabricated standard hydrogen electrode HydroFlex (experiment C4.4.3.2 (b)).





C4.4.3
ELECTROCHEMICAL POTENTIALS

C4.4.3.3
Standard potentials of non-metals

Standard potentials of non-metals (C4.4.3.3_b)

Cat.-Nr.	Name	C4.4.3.3 (a)	C4.4.3.3 (b)
664 4071	Electrochemistry demonstration unit, CPS	1	
664 401	Electrochemistry accessories set	1	
666 425	Panel frame C50, two-level, for CPS	1	
666 472	Table for electrochemistry, CPS	1	
667 7977	Electronic Balance 200 : 0,01	1	1
665 754	Measuring cylinder, 100 ml, with plastic base	1	1
673 5700	Sodium chloride, 250 g	1	1
674 6910	Hydrochloric acid, 1 mol/l, 1 l	1	
672 4920	Potassium bromide, 250 g	1	1
672 6620	Potassium iodide, 50 g	1	1
672 1901	Hexacloroplatinic acid, 5 g	1	
664 412	Standard hydrogen electrode HydroFlex		1
531 836	Universal measuring instrument, Chemistry		1
524 0621	UIP sensor S		1
664 111	Beaker, DURAN, 100 ml, tall		3
591 61	Plate electrodes, carbon, 76x40 mm, set of 5		1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair		1
501 861	Crocodile-clips, polished, set of 6		1

In experiment C4.4.3.3, the standard potentials of different non-metals are measured. This can be done either with the demonstration unit for electrochemistry (experiment C4.4.3.3 (a)) or with the Universal measuring instrument, Chemistry and the prefabricated standard hydrogen electrode HydroFlex (experiment C4.4.3.3 (b)).



C4.4.3
ELECTROCHEMICAL POTENTIALS

C4.4.3.4
Concentration potentials (Nernst equation)

Concentration potentials (Nernst equation) (C4.4.3.4)

Cat.-Nr.	Name	C4.4.3.4
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
665 996	Graduated pipette, 5 ml	1
666 003	Pipetting ball	1
664 113	Beaker, DURAN, 250 ml, tall	3
666 711	Butane gas burner	1
666 681	Tripod, 22 cm x 14 cm diam.	1
666 685	Wire gauze, 160 mm x 160 mm	1
674 8800	Silver nitrate solution, 0,1 mol/l, 250 ml	1

If two similar half-cells which differ only in the concentration c of their electrolyte solutions are combined, then a potential difference also forms between those half-cells. The general relationship is described in the Nernst equation:

$$E = E^0 + \frac{R \cdot T}{n \cdot F} \ln c(M^{n+})$$

The potential E therefore depends on the temperature in Kelvin T and on the proportionality factor R, the universal gas constant. Other parameters which play a role include the ion valence n and the Faraday constant F. The dependence on concentration and temperature are investigated in experiment C4.4.3.4.



The Daniell cell (C4.4.4.1)

C4.4.4
GALVANIC CELLS

C4.4.4.1
The Daniell cell

Cat.-Nr.	Name	C4.4.4.1
664 397	Daniell cell	1
664 4071	Electrochemistry demonstration unit, CPS	1
301 339	Stand bases, pair	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
665 793	Volumetric flask, Boro 3.3, 100 ml	4
665 997	Graduated pipette, 10 ml	2
666 003	Pipetting ball	1
672 9610	Copper(II)-sulfate-5-hydrate, 250 g	1
675 5410	Zinc sulfate-7-hydrate, 250 g	1

A galvanic cell comprises two half-cells which are connected to each other via an electrically conductive element. Each half-cell contains one electrode which is immersed in an electrolyte. The electrode material can contain metals or non-metals.

In the galvanic cell, the process is the reverse of electrolysis. Chemical energy is converted into electrical energy.

Experiment C4.4.4.1 studies the characteristics of a Cu/Zn cell (Daniell cell). In a Daniell cell, a copper plate is immersed in a copper(II)-sulfate solution and a zinc plate is immersed in a zinc sulfate solution. The solutions are separated from each other by a diaphragm (porous partition wall). The redox reaction does not begin until the copper plate and the zinc plate are connected by an electrically conductive cable.

$$Zn \rightarrow Zn^{2+} + 2\,e^-$$
$$Cu^{2+} + 2\,e^- \rightarrow Cu$$
$$\overline{\qquad\qquad\qquad\qquad}$$
$$Cu^{2+} + Zn \rightarrow Cu + Zn^{2+}$$



C4.4.4

GALVANIC CELLS

C4.4.4.2
The Leclanché cell

The Leclanché cell (C4.4.4.2)

Cat.-Nr.	Name	C4.4.4.2
664 398	Leclanché cell	1
664 4071	Electrochemistry demonstration unit, CPS	1
301 339	Stand bases, pair	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
602 010	Beaker, Boro 3.3, 150 ml, tall	1
664 131	Beaker, Boro3.3, 400 ml, squat	1
666 8471	Magnetic stirrer with hotplate	1
670 4010	Ammonium chloride, 250 g	1
674 9210	Starch, soluble, 250 g	1

The Leclanché cell is a zinc/coal battery. Here the negative pole is the steel-jacketed battery cup made of zinc. The positive pole is formed by a graphite bar which is surrounded by a mixture of graphite powder and manganese dioxide. An ammonium chloride solution (20 %) thickened by starch serves as the electrolyte. This prevents the cell from spilling out.

Experiment C4.4.4.2 demonstrates the principle of this dry cell. The voltage of the cell is first measured with the electrochemistry demonstration unit in the no-load condition. The Leclanché cell is then connected to the motor, and the voltage and current are measured simultaneously.

Reaction at the negative pole:

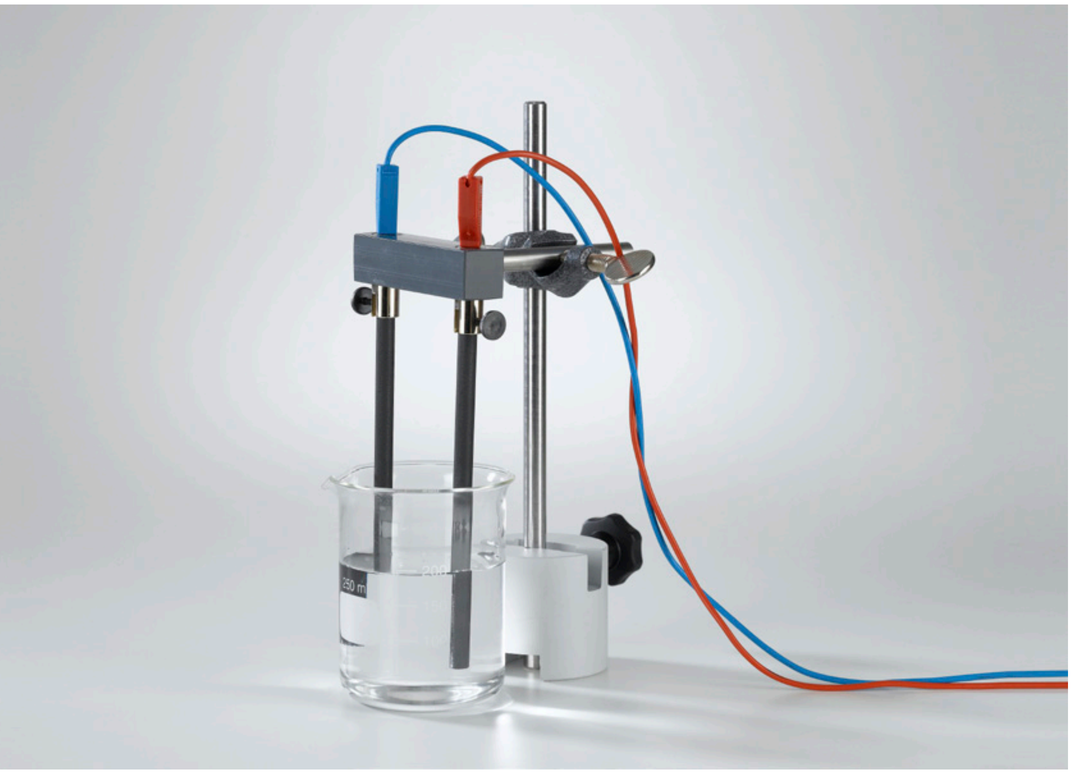
$$Zn \rightarrow Zn^{2+} + 2e^-$$

Reaction at the positive pole:

$$2MnO_2 + 2H^+ + 2e^- \rightarrow 2MnO(OH)$$

Reaction in the electrolyte solution:

$$2Zn^{2+} + 2NH_4^+ + 2Cl^- \rightarrow [Zn(NH_3)_2]Cl_2 + 2H^+$$





C4.4.5
ELECTROLYSIS

C4.4.5.1
Electrolytic polarisation

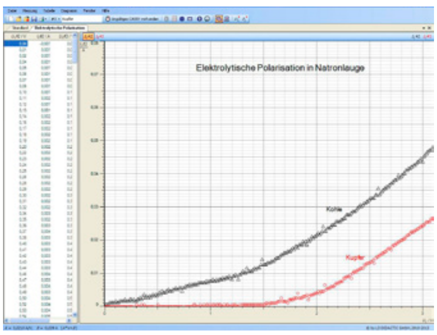
Electrolytic polarisation (C4.4.5.1)

Cat.-Nr.	Name	C4.4.5.1
524 011USB	Power-CASSY USB	1
524 220	CASSY Lab 2	1
664 373	Electrode holder	1
664 370	Rod electrodes, carbon, 150 x 8 mm diam., set of 2	1
664 374	Rod electrodes, copper, 150 x 8 mm diam., set of 2	1
664 378	Rod electrodes, zinc, 150 x 5 mm diam., set of 2	1
664 130	Beaker, Boro3.3, 250 ml, squat	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm diam.	1
301 09	Bosshead S	1
673 8410	Soda lye, 0.1 mol/l, 500ml	1
672 9660	Copper(II)-sulfate solution, 1 %, 500 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

When a direct electric current flows through an electrolyte it provokes a chemical reaction. The resulting changes in the electrolyte and the electrodes are referred to as ‚electrolysis'.

A chemical reaction can take place because the direct current provides electrons to the solution locally at the negative pole (cathode) and at the same time electrons are transferred from the solution into the electrode at the positive pole (anode). As a result, reduction takes place at the cathode and oxidation at the anode.

In experiment C4.4.5.1 the voltage during an electrolysis is raised starting from zero. Note that there is no significant flow of current until a certain voltage level is reached. That voltage is called the decomposition voltage or the deposition voltage. It is the combination of the polarisation voltage and the overvoltage. Both parameters depend on the electrode material. Different electrode materials are investigated in experiment C4.4.5.1.



Polarisation on charcoal and copper electrodes



C4.4.5

ELECTROLYSIS

C4.4.5.2
Determination of the Faraday constant

Determination of the Faraday constant (C4.4.5.2)

Cat.-Nr.	Name	C4.4.5.2
664 350	Water electrolysis unit	1
382 35	Thermometer, -10...+50 °C/0.1 K	1
531 832	Digital multimeter P	1
521 546	DC Power Supply 0 ... 16 V, 0 ... 5 A	1
501 46	Connecting leads, 19 A, 100 cm, red/blue, pair	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
665 755	Measuring cylinder, 250 ml, with plastic base	1
649 45	Tray, 552 mm x 459 mm x 48 mm	1
674 7920	Sulfuric acid, diluted, approx. 2 N, 500 ml	1

In electrolysis, the electrical conduction processes are linked to a material deposition. The quantity of material deposited is proportional to the transported charge Q which flowed through the electrolyte. In this respect, the process is an application of Faraday's law.

$$Q = n \cdot F \cdot z$$

z = valency number of ions of the substance
F = Faraday constant

Experiment C4.4.5.2 determines the Faraday constant F. For this purpose, a Hofmann voltameter is used to produce a certain quantity of hydrogen. The number of moles n of hydrogen atoms deposited can be calculated from the volume V using the ideal gas equation. At the same time, the amount of electrical charge Q required for this can be determined from the electrical work W.



Galvanisation of a metal (C4.4.6.1)

C4.4.6

GALVANIC PROCESSES IN ENGINEERING

C4.4.6.1
Galvanisation of a metal

Cat.-Nr.	Name	C4.4.6.1
664 4071	Electrochemistry demonstration unit, CPS	1
301 339	Stand bases, pair	1
664 137	Beaker, Boro3.3, 100 ml, tall	1
664 138	Beaker, Boro3.3, 250 ml, tall	1
664 382	Plate electrodes, copper, 43x28 mm, set of 10	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
501 861	Crocodile-clips, polished, set of 6	1
672 4460	Potassium lye, 1 N (1 mol/l), 1 l	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1
672 6710	Potassium sodium tartrate, 250 g	1
673 6800	Sodium hydroxide, 100 g	1
	additionally required: object to be galvanised	1

Galvanisation is a process in which objects are coated with a thin layer of metal by electrolytic means. Objects can be copper-plated, chrome-plated or silver-plated in this way.

In experiment C4.4.6.1, a thin layer of copper is applied to a metal object (e.g. a key or a nail) by means of galvanisation. In so doing, the object is wired as a cathode and immersed in a copper sulfate solution. A copper plate serves as the anode, which is also immersed in the copper sulfate solution. The process is started by applying a direct current source (3V).





C4.4.7
FUEL CELLS

C4.4.7.1
Investigation of a PEM fuel cell stack

C4.4.7.2
Recording the characteristic curves of a PEM fuel cell stack

Investigation of a PEM fuel cell stack (C4.4.7.1)

Cat.-Nr.	Name	C4.4.7.1-2
666 4812	PEM fuel cell stack, CPS	1
666 4795	HydroStik PRO, CPS	1
666 4796	HydroStik PRO	1*
666 4794	Bubble counters, CPS	1
666 4831	Electric load, CPS	1
666 4798	HydroFill PRO	1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 020USB	CASSY-Display USB	1*
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
666 425	Panel frame C50, two-level, for CPS	1
667 198	Silicone tubing, 2 mm diam., 1 m	1
666 464	Blank panel, 100 mm, CPS	2
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

Fuel cells produce extremely efficient electric current in a „silent combustion". Fuels are easily oxidised compounds such as hydrogen, hydrazine or methanol. The oxidation reaction takes place on a catalyst, usually platinum, over which the current generated is also carried. Because the fuels can be supplied continuously, it is possible - unlike with batteries - to generate electric power continuously.

Fuel cells are considered to be a technology of the future, because they are an extremely efficient means of converting the energy stored in a chemical compound into electric power. Unfortunately, however, it is not always easy to implement fuel cells in practical applications or to handle the fuels, which are usually gases.

PEM fuel cells contain a proton-conducting membrane which separates two half-cells. They require no other electrolytes, and that means that they can function with almost no liquid. Due to the low voltage that an individual fuel cell supplies, many fuel cells are wired together to form a „stack". In experiment C4.4.7.1, the function of such a fuel cell stack is studied and various circuits are compared with one another.

The performance of fuel cells is analyzed by recording so-called characteristic curves. In experiment C4.4.7.2, the characteristic curves of voltage and output are recorded for the PEM fuel cell stack. The individual cells are wired in series in part a of the experiment and they are wired in parallel in part b of the experiment.



Determination of the osmotic pressure of a sugar solution (C4.6.2.1)

C4.6.2
OSMOSIS

C4.6.2.1
Determination of the osmotic pressure of a sugar solution

Cat.-Nr.	Name	C4.6.2.1
662 403	Osmosis apparatus, large	1
667 501	Scale for large osmosis apparatus	1
664 103	Beaker, DURAN, 250 ml, squat	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
665 794	Volumetric flask, Boro 3.3, 250 ml	2
667 7977	Electronic Balance 200 : 0,01	1
665 953	Droppers, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs.	1
674 6060	D(+)-Saccharose, 250 g	1

Osmosis is a diffusion process in one direction only which occurs when two similar solutions of different concentration are separated by a semi-permeable membrane. Only molecules of the solvent can diffuse through that membrane. Molecules or ions of a dissolved substance, which are too large, are held back. In so doing, more solvent molecules diffuse into the area of higher concentration than vice versa to create equalised concentrations on both chambers.

Experiment C4.6.2.1 uses the osmometer to demonstrate the principle of osmosis. This process plays a key role in regulating the volume and water of cells. The two chambers contain different concentrations of a solution and are separated by a semi-permeable membrane. The solvent flows osmotically into the solution of higher concentration. This raises the liquid level of that solution in the open system. The higher the concentration of the solution, the greater the water ingress. It slows to a stop when the hydrostatic pressure of the water column in the capillary tube is exactly equal to the osmotic pressure.

C5 CHEMCIAL ENGINEERING



Production of sulfuric acid by the contact method (C5.1.1.1)

C5.1.1
PRODUCTION OF BASE CHEMICALS

C5.1.1.1
Production of sulfuric acid by the contact method

Cat.-Nr.	Name	C5.1.1.1
666 360	Catalytic converter	1
666 428	Panel frame C100, two-level, for CPS	1
666 4660	Adhesive magnetic board, 300 mm	6
666 4662	Spring clips, magnetic, size 3, 11...14 mm	6
666 4664	Spring clips, magnetic, size 6a, 27...29 mm	3
665 001	Funnel for gas collection	1
664 442	Evaporating dish, 80 mm diam.	1
664 800	Gas scrubber bottle, lower section, 200 ml	3
664 805	Glass tube insert, ST 29/32	3
665 392ET10	Joint clip, plastic, ST 29/32, set of 10	1
667 313	Glass connector, 1 GL 18, with glass olive	2
667 312	Glass connector, 2 x GL 18	2
665 935	Spring pressure gauge	1
667 261	Rubber stopper, one 7-mm hole, 25-31 mm diam.	1
524 009A	Mobile-CASSY	1
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
300 76	Laboratory stand II	2
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 72	Universal clamp, 0...120 mm	1
666 714	Cartridge burner, DIN type	2
375 56	Water jet pump	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
307 64	Rubber tubing, 1 m x 6 mm diam.	1
665 226	Connector, straight, 6 ... 8 mm diam.	1
608 020	Four-legged stand, rectangular, 155 x 155 x 220 mm	1
666 686	Heat protection cover plate, Ceran®, 155 mm x 155 mm	1

Cat.-Nr.	Name	C5.1.1.1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
661 243	Wash bottle, PE, 500 ml	1
602 023	Beaker, Boro 3.3, 150 ml, squat	1
665 953	Droppers, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs.	1
OHS PU401	Electronic precision balance SPU401	1
674 7510	Sulfur, cryst., 250 g	1
674 7860	Sulfuric acid, 95-98 %, 500 ml	1
672 0820	Fuchsine solution, 50 ml	1
670 7200	Barium chloride, 100 g	1
661 082	Stopcock grease, 60 g	1

Base chemicals serve as starting materials for many industrial products. In most cases they are produced in large quantities (more than 1 million tonnes per year) in optimised industrial plants.

Experiment C5.1.1.1 demonstrates the technical production of sulfuric acid by the contact method. The sulfur dioxide produced from the combustion of sulfur is oxidised by a catalyst to sulfur trioxide in the reaction tube. That is then led to water or sulfuric acid.

$$S + O_2 \rightarrow SO_2$$

SO_2 is oxidised out to SO_3 on a catalyst.

$$2\ SO_2 + O_2 \rightarrow SO_3$$

SO_3 is easily soluble in concentrated sulfuric acid. This results in disulfuric acid, which can be transformed into sulfuric acid by the addition of water:

$$H_2SO_4 + SO_3 \rightarrow H_2S_2O_7$$
$$H_2S_2O_7 + H_2O \rightarrow 2\ H_2SO_4$$



Synthesis of ammonia by the Haber-Bosch process (C5.1.1.2)

C5.1.1
PRODUCTION OF BASE CHEMICALS

C5.1.1.2
Synthesis of ammonia by the Haber-Bosch process

Cat.-Nr.	Name	C5.1.1.2
664 0772	Reaction tube, quartz, 16 cm	1
666 428	Panel frame C100, two-level, for CPS	1
666 4660	Adhesive magnetic board, 300 mm	2
666 4659	Adhesive magnetic board, 500 mm	2
667 286	Silicone stopper, one 7-mm hole, 16...21 mm diam.	2
666 4795	HydroStik PRO, CPS	1
666 4665	Spring clips, magnetic, size 7a, 30...32 mm	2
666 4661	Spring clips, magnetic, size 2, 9...11 mm	2
666 9881	Combustion boat, glazed	1
667 194	Silicone tubing, 7 mm diam., 1 m	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
667 198	Silicone tubing, 2 mm diam., 1 m	1
604 510	Hose connector, 4...15 mm	1
665 914	Gas syringe, 100 ml with 3-way stopcock	2
666 714	Cartridge burner, DIN type	1
666 731	Gas igniter, mechanical	1
667 312	Glass connector, 2 x GL 18	1
300 76	Laboratory stand II	1
666 4798	HydroFill PRO	1
660 980	Fine regulating valve for minican gas canisters	1
661 000	Minican pressurised gas canister, nitrogen	1
667 034	Tweezers, blunt, 200 mm	1
667 7933	Pocket Balance JE500	1
MA9 0201	Universal indicator paper, roll	1
602 002	Test tubes, DURAN, 16 x 160 mm, set of 100	1
667 032	Test tube holder, wooden, 40 mm diam.	1
608 350	Mortar, 50 ml	1

Cat.-Nr.	Name	C5.1.1.2
608 360	Pestle, 52 mm long	1
664 154	Watch glass dish, 80 mm diam.	1
602 032	Beaker, DURAN, 150 ml, tall	1
661 243	Wash bottle, PE, 500 ml	1
661 251	Flip-flap glass, 20 ml	1
671 8300	Iron powder, reduced, 50 g	1
670 2900	Aluminium oxide, 250 g	1
671 3200	Calcium oxide, powder, 100 g	1
672 6800	Potassium nitrate, 100 g	1

The Haber-Bosch process is the most important process for the production of ammonia. It was developed by the chemist Fritz Haber and the engineer Carl Bosch and was already being used in industrial scale operations in 1913.

$3\,H_2 + N_2 \rightleftharpoons 2\,NH_3$

Ammonia is synthesised here from molecular nitrogen and hydrogen. A catalyst is required in order to speed up the rate of reaction.

Experiment C5.1.1.2 uses the catalyst developed by Mittasch (iron powder, aluminium oxide, calcium oxide and potassium nitrate) in order to produce small quantities of ammonia even at normal pressure. The ammonia can be assayed using the base reaction on indicator paper.



Extraction of iron by the blast furnace process (C5.1.2.1)

C5.1.2
EXTRACTION OF METALS FROM ORE

C5.1.2.1
Extraction of iron by the blast furnace process

Cat.-Nr.	Name	C5.1.2.1
661 541	Blast furnace model	1
664 752	Mini-compressor, electric	1
521 55	High current power supply	1
300 02	Stand base, V-shaped, small	1
301 26	Stand rod, 25 cm, 10 mm diam.	1
301 09	Bosshead S	1
301 72	Universal clamp, 0...120 mm	1
667 104	Cover plate, 50 cm x 50 cm	1
665 223ET10	Connector, T-shaped, 8 mm diam., 10 pieces	1
667 180	Rubber tubing, 1 m x 7 mm diam., DIN 12865	1
667 176	Hofmann tubing clamp, 30 mm	1
671 8810	Peroxide of iron (haematite), 250 g	1
670 2020	Activated charcoal, granulated, 500 g	1
672 2490	Charcoal, small pieces, 500 g	1
672 1000	Glass wool, 10 g	1

Metal is certainly the most commonly used material in the manufacture of tools, weapons and jewellery. Hardly any other material has so profoundly marked human development.

Iron does not exist on the Earth as an element, but rather in the form of its oxides and sulphides in iron ore. They are the starting materials for the technical extraction of pig iron in the blast furnace.

The blast furnace operates at 1900 °C in order to smelt iron from iron ore. To attain that temperature, coke (and not coal) is used as fuel, and the fire inside the furnace is fanned with hot air at 1200 °C to 1300 °C degrees. Lime is added as an additional component; it binds contaminants. The blast furnace is fed from the top, so that alternating layers of coke and iron ore are formed. The highest temperature occurs in the lower part of the furnace. The liquid iron, on which the slag floats, collects at the base.

About once every two or three hours, the furnace is „tapped". First the slag is allowed to flow out, and then the glowing yellow pig iron at about 1450 °C. The toxic waste gases (blast furnace gases) rise, are fed into a gas purification system, and heat the supply air for the furnace.

Experiment C5.1.2.1 uses the blast furnace model to demonstrate the reduction of iron ore in a way that is similar to the industrial scale process. Depending on the ore used and the reaction conditions (temperature, air supply, additives), the resulting reaction product is a mixture of different proportions of slag, partially reduced iron ore (Fe_3O_4) and metallic iron.



The thermite process (C5.1.2.2)

C5.1.2
EXTRACTION OF METALS FROM ORE

C5.1.2.2
The thermite process

Cat.-Nr.	Name	C5.1.2.2
661 540	Thermite experiment	1
666 714	Cartridge burner, DIN type	1
666 731	Gas igniter, mechanical	1

Experiment C5.1.2.2 demonstrates the principle of the thermite process. In engineering, the thermite process is used to weld railway tracks together. A mixture of aluminium grit and iron(II, III) oxide is added to the apparatus and lit with an ignition rod. Liquid iron and aluminium oxide form in a very exothermic reaction. The iron has a higher density than aluminium oxide and so it sinks down in the melt.

$$Fe_2O_3 + 2\,Al \rightarrow 2\,Fe + Al_2O_3$$

Because aluminium releases immense quantities of energy in the reaction with oxygen, the reaction needs only to be started with an igniter. The energy released drives the rest of the process, and along with that it also liquefies the resulting iron.



Production and use of indigo (C5.2.4.1)

C5.2.4
PIGMENTS AND DYESTUFFS

C5.2.4.1
Production and use of indigo

Cat.-Nr.	Name	C5.2.4.1
664 246	Erlenmeyer flask, DURAN, 100 ml, wide neck	1
665 161	Büchner funnel, 45 mm diam.	1
661 030	Round filter, type 595, 40 mm diam., 100 pcs.	1
665 060	Rubber collars, set of 7	1
664 865	Suction flask, 250 ml, glass	1
382 21	Stirring thermometer, -30...+110 °C	1
666 967	Spoon-ended spatula, stainless steel, 150 mm	1
665 751	Measuring cylinder, 10 ml, with plastic base	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
665 996	Graduated pipette, 5 ml	3
666 003	Pipetting ball	1
665 953	Droppers, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs.	1
664 103	Beaker, DURAN, 250 ml, squat	1
664 101	Beaker, DURAN, 100 ml, squat	2
664 154	Watch glass dish, 80 mm diam.	1
667 7977	Electronic Balance 200 : 0,01	1
375 56	Water jet pump	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
666 839	Magnetic stirrer with hot plate	1
673 9390	2-Nitrobenzaldehyde, 5 g	1
670 0410	Acetone, 1 l	1
673 8420	Soda lye, 1 mol/l, 500 ml	1
671 9711	Ethanol, absolute, 500 ml	1
671 6700	Diethylether, 250 ml	1
673 6310	Sodium dithionite, 250 g	1
673 6810	Sodium hydroxide, pellets, 250 g	1
	additionally required: white cotton cloth	1

Synthetic dyes have been known since the middle of the 19th century. Many major chemical companies started out as dye producers. The first dyes were extracted from tar. Today most dyes are based on crude oil.

Chemical compounds are coloured when they absorb wavelengths from the visible range of the spectrum. The compound then appears in the complementary colour of the absorbed wavelength.

Along with their colour, the ability to colour materials more or less colourfast is a decisive feature of dyes. That colouring is done by binding the dyes to the carrier materials or having the dyes penetrate into them. This, too, can be influenced by chemical means.

Experiment C5.2.4.1 synthesizes indigo, the dye used to colour jeans. Developed by Adolf von Baeyer in 1870, this synthesis was one of the first dye syntheses to be applied on an industrial scale. The educt used is nitrobenzaldehyde, which condenses with acetone under base conditions. The reduced, soluble leuco form of the dye is insolubly anchored in the tissue through oxidation by air.



Catalytic purification of automobile exhaust gases (C5.3.1.2)

C5.3.1
WASTE GAS PURIFICATION

C5.3.1.1
Analysis of waste gases

C5.3.1.2
Catalytic purification of automobile exhaust gases

Cat.-Nr.	Name	C5.3.1.1	C5.3.1.2
665 914	Gas syringe, 100 ml with 3-way stopcock	3	2
667 312	Glass connector, 2 x GL 18	3	3
666 313	Testing tube for NO_x, 0.5...50 ppm, set of 10	1	
666 319	Testing tube for CO, 0.5...7.0 %, set of 10	1	
666 314	Testing tube for SO_2, 1...25 ppm, set of 10	1	
667 015	Glass file, triganular	1	
666 360	Catalytic converter		1
665 912	Gas syringe, 100 ml		2
665 255	Three-way valve, T-shaped, ST nozzles		2
524 009A	Mobile-CASSY		1
524 0673	NiCr-Ni adapter S, type K		1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K		1
666 425	Panel frame C50, two-level, for CPS		1
666 4659	Adhesive magnetic board, 500 mm		2
666 4661	Spring clips, magnetic, size 2, 9...11 mm		2
666 4662	Spring clips, magnetic, size 3, 11...14 mm		1
666 4665	Spring clips, magnetic, size 7a, 30...32 mm		2
656 016	Bunsen burner, universal		1
607 020	Safety gas hose with clamp, 0.5 m		1
300 76	Laboratory stand II		1
	additionally required: exhaust sample, such as car exhausts or cigarette smoke	1	
	additonally required: exhaust sample or a self produced exhaust mixture made of nitrogen dioxide and methane or carbon monoxide		2

The fossil energy carriers coal, oil and natural gas are primarily used as fuels. The combustion processes generate waste gases which enter the atmosphere and are harmful to the environment and to human health. Carbon dioxide (CO_2) intensifies the greenhouse effect, for example, and sulfur dioxide (SO_2) and nitrogen oxides (NO_x) cause acid rain. Today pollution emissions are strictly controlled. Plant operators must reduce their emissions. Catalytic converters are a mandatory feature of automotive exhaust systems.

Under ideal conditions, the combustion of hydrocarbons would generate only water and carbon dioxide. When it involves a mixture of different fuels, e.g. petrol, then combustion can also produce nitrogen oxides or sulphur oxides. Experiment C5.3.1.1 uses detection tubes to test for the presence of such byproducts in different waste gases.

The so-called ‚three-way catalyst' removes the three most important toxic substances from automotive exhaust simultaneously: unburned hydrocarbons, carbon monoxide and nitrogen oxides. It consists of a ceramic carrier to which noble metals such as platinum and palladium are applied. The reactions which take place include the following:

$$CH_4 + 2\,NO_2 \rightleftharpoons CO_2 + 2\,H_2O + N_2$$
$$4\,CO + 2\,NO_2 \rightleftharpoons CO_2 + N_2$$
$$2\,CO + 2\,NO \rightleftharpoons 2\,CO_2 + N_2$$

In experiment V5.3.1.2, waste gases are purified with a three-way catalyst. The waste gas used in the investigation can be either automotive exhaust or a self-made mixture of waste gases.





C5.3.2
GLOBAL ENVIRONMENTAL PROBLEMS

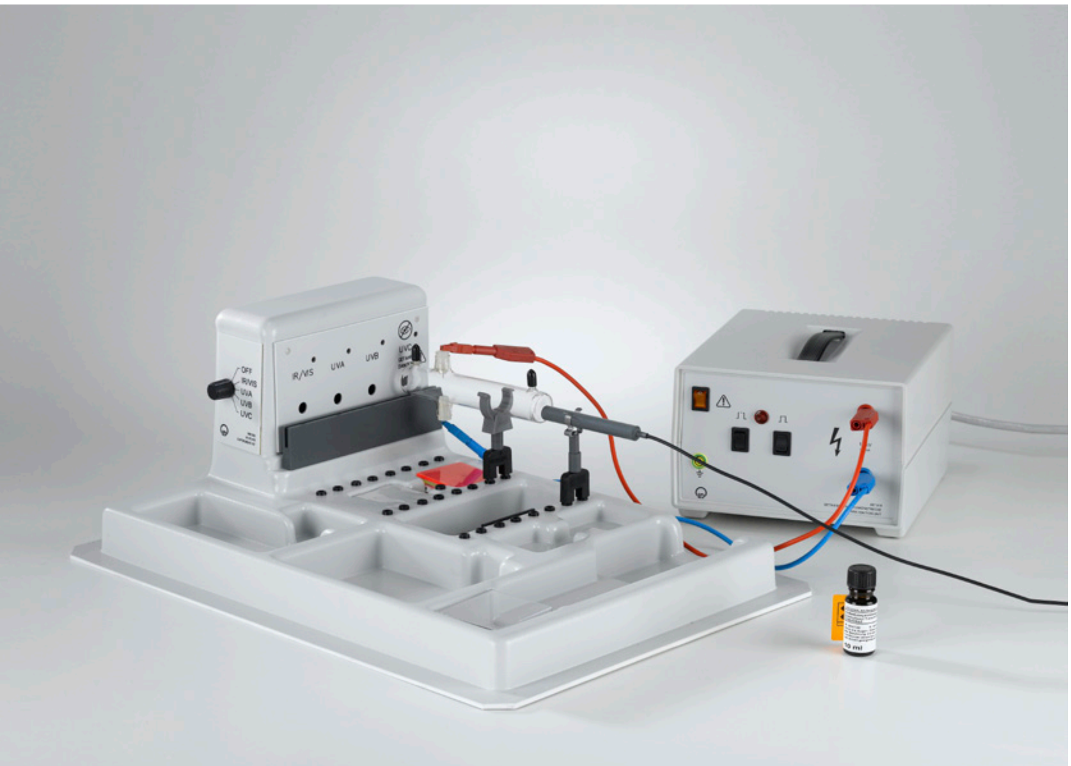
C5.3.2.1
Greenhouse effect

Greenhouse effect (C5.3.2.1)

Cat.-Nr.	Name	C5.3.2.1
666 2651	IR-CO_2 experiment set	1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0511	Lux adapter S	1
666 248	IR-CO_2 sensor	1
524 045	Temperature box, NiCr-Ni/NTC	1
666 216	Temperature probe, NiCr-Ni, fast	1
521 535	DC power supply, 2 x 0...16 V/0...5 A	1
660 999	Minican pressurised gas canister, carbon dioxide	1
660 980	Fine regulating valve for minican gas canisters	1
667 197	Silicone tubing, 4 mm diam., 1 m	1

The Earth's climate is determined by a complex interaction of numerous factors. Many of those factors mutually affect and strengthen one another. As a result, the climate is subject to constant fluctuations on all time scales, from decades to millions of years. Today humans are intervening in this self-regulating system to a massive extent.

In experiment C5.3.2.1, the IR-CO_2 experimentation kit is used to demonstrate the absorption of infrared (IR) radiation by CO_2 in the wavelength range from 4100 to 4300 nm. The short-wave radiation of the Sun penetrates water vapour, carbon dioxide, ozone, nitrous oxide and methane in the Earth's atmosphere and reaches the surface of the Earth unimpeded. The long-wave heat radiation is absorbed. Acting like the glass of a greenhouse, the greenhouse gases impede the release of energy from the Earth and cause heat to build up. Only a small part of the heat radiation is emitted directly into space - the far greater share is reflected back toward the surface of the Earth. This is referred to as the natural greenhouse effect. The proportion of greenhouse gases is changing as a result of human activity. The associated temperature increase is referred to as the anthropogenic greenhouse effect.





C5.3.2
GLOBAL ENVIRONMENTAL PROBLEMS

C5.3.2.2
Ozone hole problem

Ozone hole problem (C5.3.2.2)

Cat.-Nr.	Name	C5.3.2.2
666 265	UV-IR-VIS experiment kit	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 0511	Lux adapter S	1
666 246	UV-C sensor	1
667 818	Spark gap supply unit	1
500 621	Safety connection lead, 50 cm, red	1
500 622	Safety connection lead, 50 cm, blue	1
667 489	Crocodile clips, insulated, set of 2	1
667 241	Rubber bellows, single bulb	1
665 957	Disposable syringe, 1 ml, with Luer fitting	1
603 030	Cannulae, 0.6 mm diam., set of 10	1
671 6600	Dichloromethane, 250 ml	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

In experiment C5.3.2.2, the UV-IR-VIS experimentation kit is used to demonstrate the absorption of UV-C radiation by ozone and the formation and decomposition of ozone. The ozone layer in the stratosphere (at a height of 15 to 50 km) is vitally important to life on Earth. Without its protective effect, strong short-wave UV radiation would make life outside of water impossible. The ozone layer acts as a filter for radiation from 220 to 310 nm. As a result it completely absorbs UV-C radiation (220 nm to 280 nm) and absorbs most of the UV-B radiation (280 nm to 320 nm).

For that reason, a reduction in the ozone concentration (ozone depletion, „ozone hole“) is increasing the intensity of biologically effective UV-B radiation. This can damage plants, thereby reducing harvest yields. Phytoplankton (types of algae at shallow ocean depths) are also affected – an important link in the food chain of the sea. Because it also absorbs a considerable quantity of carbon dioxide, it represents an integral part of the carbon cycle and plays a role in the greenhouse effect. Ozone forms in the stratosphere by the effect of hard UV radiation on oxygen.



Production of fuel from rapeseed oil (C5.4.1.1)

C5.4.1
FUELS

C5.4.1.1
Production of fuel from rapeseed oil

C5.4.1.2
Analysis of fuel from rapeseed oil

Cat.-Nr.	Name	C5.4.1.1	C5.4.1.2
666 8471	Magnetic stirrer with hotplate	1	
666 851	Stirring magnet, 25 mm x 6 mm diam.	1	
666 850	Stirring magnet, 15 mm x 5 mm diam.	1	
602 004	Test tubes, DURAN, 20 x 180 mm, set of 100	1	
667 053	Test tube rack, for 10 tubes, 22 mm diam.	1	
664 103	Beaker, DURAN, 250 ml, squat	1	
602 022	Beaker, Boro 3.3, 100 ml, squat	1	
300 02	Stand base, V-shaped, small	1	
608 050	Stand tube, 300 mm, diam. 10 mm	1	
301 09	Bosshead S	2	
666 555	Universal clamp, 0...80 mm	2	
382 21	Stirring thermometer, -30...+110 °C	1	
665 953	Droppers, 7 x 150 mm, 10 pcs.	1	
665 954	Rubber bulbs, 10 pcs.	1	
665 995	Graduated pipette, 2 ml	1	
665 996	Graduated pipette, 5 ml	1	
666 003	Pipetting ball	1	
667 257	Rubber stopper, solid, 19...24 mm diam.	1	
667 258	Rubber stopper, one 7-mm hole, 19...24 mm diam.	1	
665 204	Glass tube, 300 mm x 8 mm diam.	1	
673 2700	Methanol, 250 ml	1	
673 6800	Sodium hydroxide, 100 g	1	
665 906	Höppler falling ball viscometer		1
313 07	Hand-held stop-watch I, mechanical		1
666 7681	Circulation thermostat SC 100-S5P		1
667 194	Silicone tubing, 7 mm diam., 1 m		2

Cat.-Nr.	Name	C5.4.1.1	C5.4.1.2
675 3410	Water, pure, 5 l		2
	additionally required: rapeseed oil	1	
	biodiesel from rapeseed oil produced in experiment C5.4.1.1		1

Rising energy demand ushered in by the industrial age in combination with the continuously increasing world population have caused worldwide consumption of fossil fuels such as oil, natural gas and coal to increase by more than twenty-fold over the past 100 years. The resulting shortage of fossil fuels demands, along with more frugal use of energy, the search for equivalent renewable sources of energy, including the suitable eco-friendly fuels.

In experiment C5.4.1.1, sodium methoxide is used to produce biodiesel from rapeseed oil. In this reaction, the rapeseed oil is first split into glycerine and fatty acids, and then esterified with methanol (transesterification) in a second step. The rapeseed acid-methylesters produced in this way represent the actual biodiesel.

Experiment C5.4.1.2 determines the viscosity of fuel made from rapeseed oil. For this purpose, the temperature control chamber of the viscometer is connected to a recirculation thermostat and the viscosity is measured in relation to temperature.

C6 BIOCHEMISTRY



C6.1.1
CARBOHYDRATES

C6.1.1.1
Test for reducing sugar - Fehling's reaction

Test for reducing sugar - Fehling's reaction (C6.1.1.1)

Cat.-Nr.	Name	C6.1.1.1
666 8471	Magnetic stirrer with hotplate	1
382 33	Thermometer, -10...+150 °C/1 K	1
665 793	Volumetric flask, Boro 3.3, 100 ml	2
665 212ET10	Glass stirring rod, 200 mm x 8 mm diam., set of 10	1
664 137	Beaker, Boro3.3, 100 ml, tall	1
664 132	Beaker, Boro3.3, 600 ml, squat	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
667 7977	Electronic Balance 200 : 0,01	1
665 997	Graduated pipette, 10 ml	1
666 003	Pipetting ball	1
664 045	Test tubes, Fiolax, 30 x 200 mm, set of 10	1
667 054	Test tube rack, for 12 tubes, 32 mm diam.	1
664 155	Watch glass dish, 100 mm diam.	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
661 243	Wash bottle, PE, 500 ml	1
672 1100	D(+)-Glucose, 100 g	1
672 0700	D(-)-Fructose, 50 g	1
674 6050	D(+)-Saccharose, 100 g	1
672 6710	Potassium sodium tartrate, 250 g	1
673 6800	Sodium hydroxide, 100 g	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1
674 6750	Hydrochloric acid concentrated, 25 %, 250 ml	1
670 9160	Boiling stones, 250 g	1

Carbohydrate is the collective name for a broad-ranging group of natural substances to which all types of sugar, starch and cellulose belong. They have the general molecular formula $C_n(H_2O)_m$ (n and m either equal or only slightly different), which is why they were previously erroneously regarded as „hydrates of carbon". Carbohydrates are polyalcohols, in which a primary or a secondary hydroxyl group is oxidised to the aldehyde group or the ketone group (carbonyl group).

Fehling's solution was developed by Herrmann Fehling in 1848. It is a reaction for the detection of reducing groups, such as aldehyde functions, for example. It makes it possible to differentiate between reducing and non-reducing sugars. Originally it was also used to determine blood sugar content in diabetics by means of titration.

Experiment C6.1.1.1 uses the Fehling reagent to analyse glucose, fructose and sucrose.





C6.1.2

AMINO ACIDS AND PROTEINS

C6.1.2.1
Enzymatics: Splitting urea with urease

C6.1.2.2
Michealis-Menten kinetics using the enzyme urease

Enzymatics: Splitting urea with urease (C6.1.2.1)

Cat.-Nr.	Name	C6.1.2.1	C6.1.2.2
524 018	Pocket-CASSY 2 Bluetooth	1	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*	1*
524 0031	Bluetooth dongle	1*	1*
524 220	CASSY Lab 2	1	1
524 0671	Conductivity adapter S	1	1
529 670	Conductivity sensor	1	1
607 105	Magnetic stirrer mini	1	1
300 11	Saddle base	1	1
301 26	Stand rod, 25 cm, 10 mm diam.	1	1
666 543	Double bosshead	1	1
666 555	Universal clamp, 0...80 mm	1	1
602 010	Beaker, Boro 3.3, 150 ml, tall	2	2
665 997	Graduated pipette, 10 ml	1	1
666 003	Pipetting ball	1	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1	1
664 153	Watch glass dish, 60 mm diam.	2	2
602 680	Powder funnel, glass, 50 mm diam.	2	2
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1	1
667 253	Rubber stopper, solid, 14...18 mm diam.	2	2
667 050	Test tube rack, plastic, for 9 tubes, 18 mm diam.	1	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1	1
667 7977	Electronic Balance 200 : 0,01	1	1
670 3900	Ammonium carbonate, 100 g	1	
672 1700	Urea, 100 g	1	1
675 2810	Urease (1 U/mg), 5 g	1	1
672 9600	Copper(II)-sulfate-5-hydrate, 100 g	1	
675 3400	Water, pure, 1 l	1	1

* additionally recommended

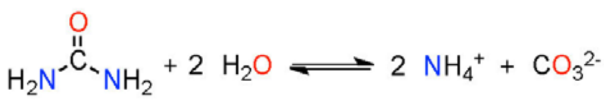
Proteins are the biomolecules made of amino acids. In nature there are 20 amino acids which have been found in proteins (proteinogenic amino acids). Proteinogenic amino acids are α-amino acids. They are carbonic acids, which have an amino group in the α position (nearest C atom).

In protein synthesis, the carbonic acid group of the one amino acid reacts with the amino function of the next one in a condensation reaction. A peptide bond is formed. Amino acids can be linked in nearly any sequence via peptide bonds. This is why there is such a large number of different proteins.

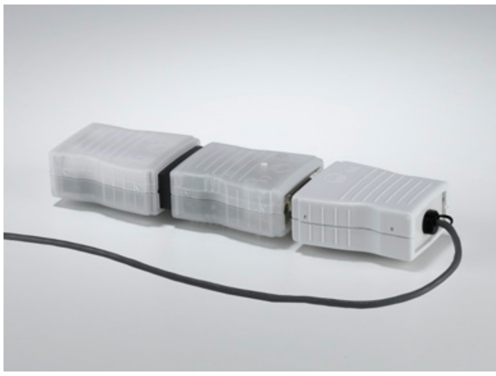
Proteins are the building blocks of the cell. A distinction is drawn between scaffold proteins, which provide stability, and globular, soluble proteins. The subgroup of globular proteins includes enzymes, which catalyse reactions. They play an important role in the digestion of food, for example.

Experiment C6.1.2.1 takes a closer look at the enzyme urease. Urease splits urea into ammonia and carbonate ions. Since the urea solution does not conduct electricity, but a solution with ammonia and carbonate does, the course of the reaction can be recorded with conductivity measurements. The maximum rate of reaction and the reaction order are determined. Also an inhibitor is tested.

In experiment C6.1.2.2 the kinetics of the enzyme urease are examined. The rate of the reaction with different starting concentration is measured. Applying Michaelis-Menten kinetics, the maximal reaction rate v_{max} and the michaelis constant K_m can be determined.







C6.1.4
FATS AND OILS

C6.1.4.1
Determination of the calorific value of olive oil with a demonstration calorimeter

Determination of the calorific value of olive oil with a demonstration calorimeter (C6.1.4.1)

Cat.-Nr.	Name	C6.1.4.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 044	Temperature sensor S, NTC	1
667 325	Calorimeter for solids and liquids	1
666 603	Base rail, 95 cm	1
666 615	Universal bosshead	3
666 609ET2	Stand tubes, 450 mm, 10 mm diam. , set of 2	2
666 555	Universal clamp, 0...80 mm	2
301 72	Universal clamp, 0...120 mm	1
301 09	Bosshead S	4
664 800	Gas scrubber bottle, lower section, 200 ml	2
664 805	Glass tube insert, ST 29/32	1
664 806	Glass tube insert with filter, ST 29/32	1
665 392ET10	Joint clip, plastic, ST 29/32, set of 10	1
521 546	DC Power Supply 0 ... 16 V, 0 ... 5 A	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
307 65	Rubber tubing, 1 m x 7 mm diam.	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
604 510	Hose connector, 4...15 mm	1
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1
SAT E2101	Electronic precision balance, TE2101	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

Nutritional fats differ in their consistency. At room temperature some are solid, others are spreadable, and many are liquid. Liquid fats are referred to as oils. Fats are less dense than water and insoluble in water. In non-polar solvents, on the other hand, they dissolve readily. So fats are non-polar.

Fats represent the most energy-rich group of the foods which are vital for the human organism. The mean physiological calorific value of fats is about 38.8 kJ/g. Apart from the supply of energy, however, the significance of fats lies also in the transport and resorption of fat-soluble vitamins and in the enhanced flavour of our dishes.

In experiment C6.1.4.1, the calorific value of olive oil is determined. For this purpose, olive oil is burned in an O_2 atmosphere and the temperature rise is measured in the calorimeter. A filament is used to ignite the oil. The energy released is calculated using either a previously determined heat capacity of the filled calorimeter or the individual theoretical values of the heat capacities of the glass jacket and calorimeter liquid. The quantity of heat Q is calculated according to the following formula:

$$Q = \Delta T \times (m_k \times C_k + m(H_2O) \times C(H_2O))$$

Here ΔT represents the temperature difference, m_k and $m(H_2O)$ are the mass of the calorimeter and of the water, and C_k and $C(H_2O)$ are the heat capacities of the glass apparatus and the water. In order to calculate the heat of combustion ΔH, the ignition energy, which also contributed to the heating of the apparatus, must be subtracted. The quantity of heat is then expressed relative to one mol of substance.





C6.2.1
BIOTECHNOLOGICAL PROCESSES

C6.2.1.1
Yeast fermentation - Test of oxygen consumption

Yeast fermentation - Test of oxygen consumption (C6.2.1.1)

Cat.-Nr.	Name	C6.2.1.1
524 018	Pocket-CASSY 2 Bluetooth	1
524 220	CASSY Lab 2	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 0521	Oxygen adapter S	1
667 458	Oxygen electrode	1
386 40	Dewar flask, clear, for demonstration	1
607 105	Magnetic stirrer mini	1
666 851	Stirring magnet, 25 mm x 6 mm diam.	1
300 11	Saddle base	2
300 41	Stand rod, 25 cm, 12 mm diam.	2
666 555	Universal clamp, 0...80 mm	2
301 09	Bosshead S	2
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
604 510	Hose connector, 4...15 mm	1
307 64	Rubber tubing, 1 m x 6 mm diam.	1
665 953	Droppers, 7 x 150 mm, 10 pcs.	1
667 7977	Electronic Balance 200 : 0,01	1
604 5661	Spatula, double ended, 185 mm	2
665 752	Measuring cylinder, 25 ml, with plastic base	1
665 754	Measuring cylinder, 100 ml, with plastic base	1
602 355	Laboratory bottle 250ml, ISOthread 45	1
602 725	Laboratory dish, 140 mm diam., 900 ml	1

Cat.-Nr.	Name	C6.2.1.1
664 103	Beaker, DURAN, 250 ml, squat	1
661 242	Wash bottle, PE, 250 ml	1
672 1100	D(+)-Glucose, 100 g	1
	additionally required: PC with Windows XP/Vista/7/8	1

* additionally recommended

In biotechnology, products are produced with the aid of microorganisms. This occurs in large vessels known as bioreactors. Bioreactors can be operated in batches (batch processing) or continuously. In any case, successful culture relies on understanding the growth conditions of microorganisms.

Experiment C6.2.1.1 verifies the respiration in a yeast fermentation by measuring the oxygen consumption. For this purpose, a yeast suspension is saturated with oxygen. Then the oxygen supply is shut off and the oxygen saturation is tracked.



Production of yoghurt (C6.2.2.3)

C6.2.2
BIOTECHNOLOGICAL PRODUCTS

C6.2.2.3
Production of yoghurt

Cat.-Nr.	Name	C6.2.2.3
665 563ET5	Miniature separation tank 250 ml, set of 5	1
382 33	Thermometer, -10...+150 °C/1 K	1
666 767	Hotplate, 1500 W, 180 mm diam.	1
607 0721	Bath vessel, stainless steel	1
666 8061	Drying Oven/Hot Air Sterilizer E 28	1
666 966	Spoon-ended spatula, PP, 180 mm	1
665 753	Measuring cylinder, 50 ml, with plastic base	1
MA9 0201	Universal indicator paper, roll	1
	additionally required: 1 l of milk (UHT) and plain yoghurt	1

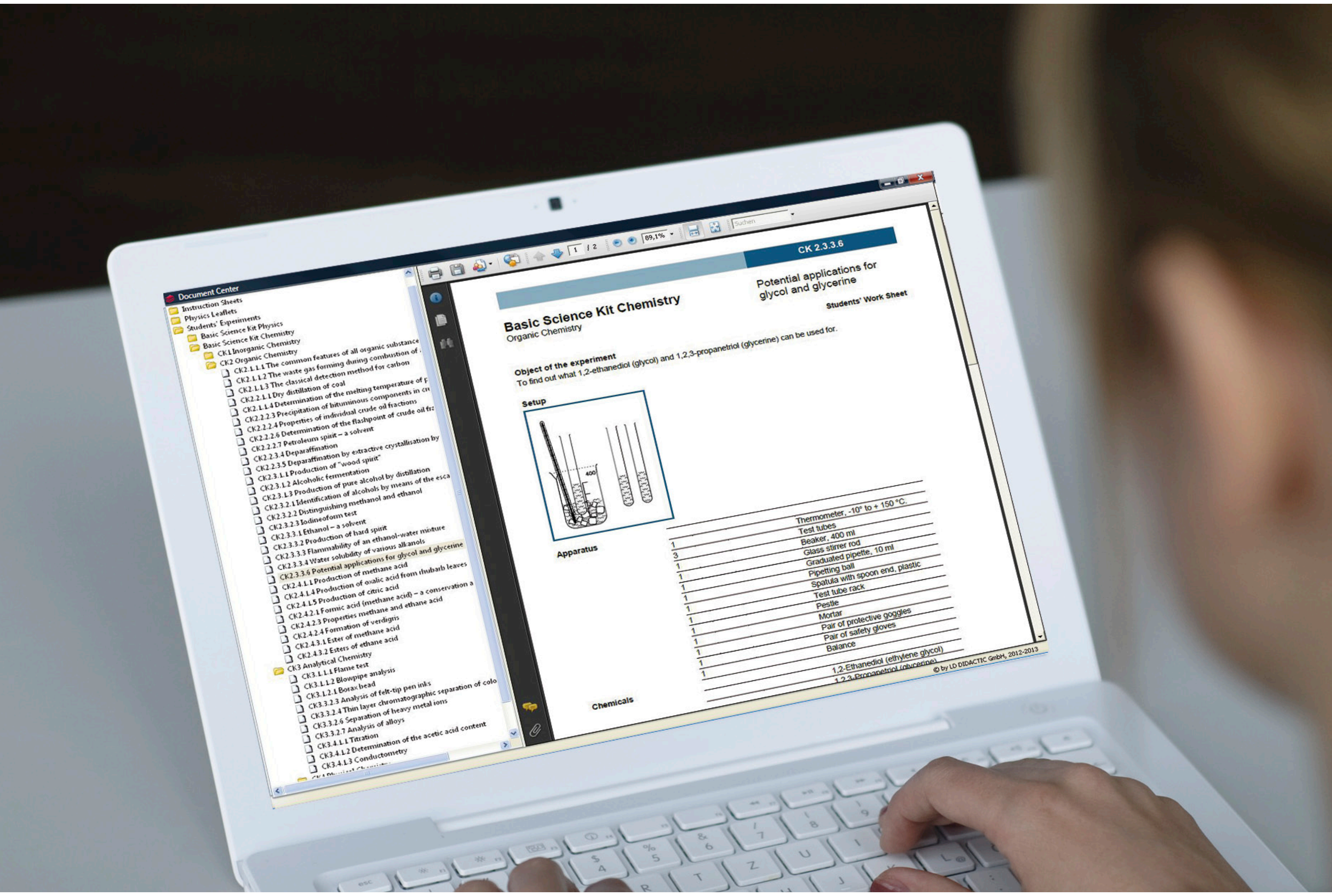
For thousands of years now, humans have been using biotechnology to produce food, textiles and other commodities. A whole series of perfectly ordinary, everyday things – including leavened bread, yoghurt, cheese, wine, beer and vinegar – are produced with the help of cultivated microorganisms.

Biotechnology is a technology which uses the living organism or parts of it to manufacture or modify products.

In experiment C6.2.2.3, yoghurt is produced from milk. If some yoghurt or isolated cultures of *Lactobacillus bulgaricus* (lactic acid bacteria) and possibly *Streptococcus themophilus* are added to milk, then the milk will become yoghurt. Yoghurt is the end product of an anaerobic bacteria metabolism. Lactic acid bacteria ferment in the lactose contained in the milk. The latter is first split into glucose and galactose by the enzyme lactase. Those cleavage products are then transformed into lactic acid by glycolysis and lactic acid fermentation.

APPENDIX

EXPERIMENT INSTRUCTIONS



THE DOCUMENT CENTER IS THE ELECTRONIC LEYBOLD LIBRARY

- For information on experiments for students and demonstration experiments
- For operation manuals

DOWNLOAD THE DOCUMENT CENTER FREE OF CHARGE: WWW.LD-DIDACTIC.COM

IN THE DOCUMENT CENTER

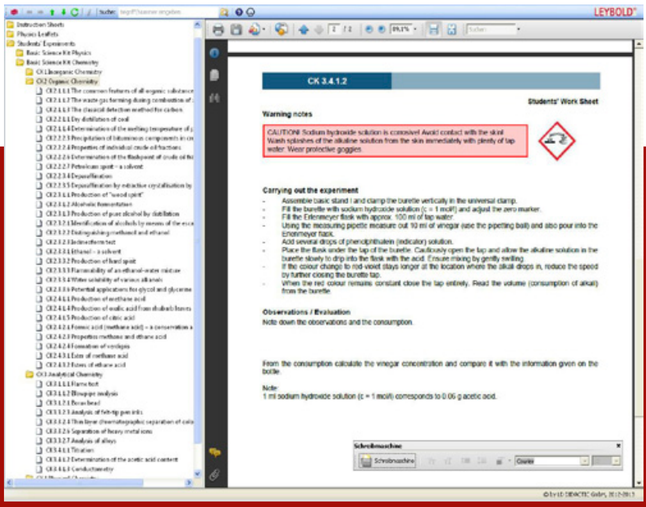
THE DOCUMENT CENTER OFFERS

- Handout sheets (demonstration instructions) with link to CASSY LAB 2 and SpektraLab
- Experiments for students as interactive pdf files:
  - Easy-to-understand worksheets for students
  - Complete information with experiment results for teachers
  - Ability to go from student to teacher version and back with one mouse click
  - Student documents can be filled out on the computer and stored or printed out as a protocol
- Sorted into literature packages – facilitates and encourages the compilation of own test series
- Free-of-charge online update of literature packages following initial acquisition

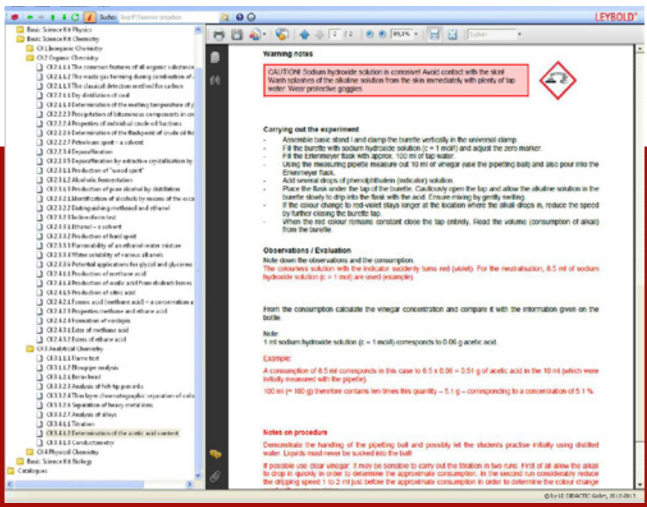
HOW DOES IT WORK?

The literature packages are clearly displayed in a table of contents, which is structured to guide you to the document you need. The more literature packages you have installed, the more entries are listed in the table of contents. Once the system has been installed, the documents can be set to update automatically if desired.

The convenient, fault-tolerant search function helps you find the right document rapidly.



Student version with typewriter tool for filling out protocols on the computer



Teacher version with an example of the solution and notes about the experiments

A

B

C

D



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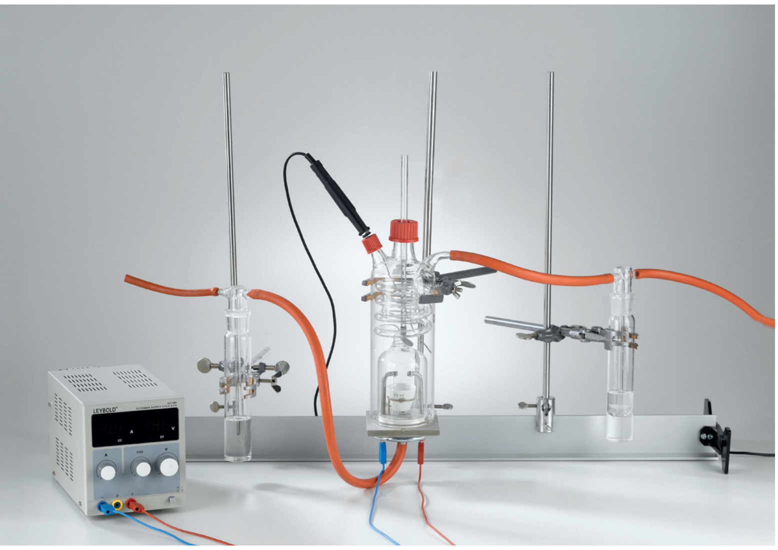
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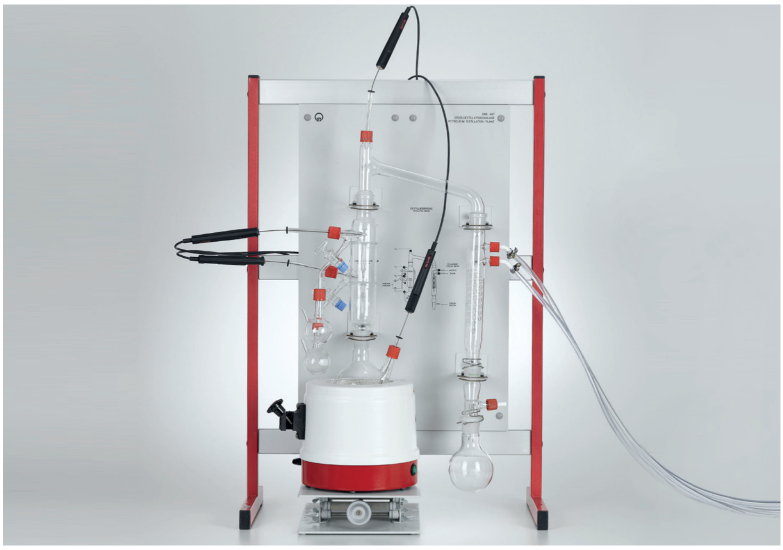
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